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CONCEPTS FOR THE ANALYSIS OF COMMAND, CONTROL AND COMMUNICATIONS (C^3) IN NATO ASW EXERCISES AND OPERATIONS

by
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by

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This report has been prepared as part of Project 06.

APPROVED FOR DISTRIBUTION

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CONCEPTS FOR THE ANALYSIS OF COMMAND, CONTROL AND COMMUNICATIONS (C^3) IN NATO ASW EXERCISES AND OPERATIONS

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John G. Pierce

ABSTRACT

This report provides an analytical description of naval command, control and communications (C^3) as a process. The relationship between C^3 and the combat process is described, and measures of effectiveness for C^3 are defined. The report then discusses the possible methods of improving C^3 as a means of increasing combat efficiency. The role of analysis in the improvement of C^3 and available analytical tools and methods are described. Finally, specific methods for the study of C^3 in maritime exercises are proposed.

PART I

BASIC CONCEPTS OF C^3 ANALYSIS

PURPOSE

This paper has three major purposes:

a. To provide an analytical description of the Command, Control and Communications (C^3) process.

b. To justify the use of analytical methods to improve maritime C^3 in NATO.

c. To provide a detailed basis for the planning and conduct of observation, data collection, reconstruction and analysis of C^3 in NATO maritime exercises as part of the overall analytical approach to improving C^3.

SCOPE

Much of the discussion in this paper is sufficiently general to apply to maritime C^3 in the broadest sense. Where limitation of scope is necessary, however, the discussion is focussed on tactical C^3 of ASW operations.

C^3 AS A PROCESS

C^3 means many things to many people. Some people emphasize the organization; some emphasize the C^3 system. Other people emphasize hardware as the essence of C^3; still others focus on software and procedures. From the analytical viewpoint it seems most natural to think of C^3 as a process that is continuous and dynamic and that incorporates all of the above factors in a balanced way; this latter point of view will be pursued.

Abstractly, warfare can be treated as a process as represented in Fig. 1. The essential features of this process are the COMBAT SITUATION, which evolves as a result of the interactions of RED and BLUE forces and the two symmetrical loops that incorporate the sequence of INFORMATION/COMMAND/-ACTION by both RED and BLUE. Also shown are the possible actions by each side against the C^3 system of the opponent.

The sub-processes represented in this diagram are continuous and evolving. As the COMBAT SITUATION changes, each side must employ its C^3 SYSTEM to estimate the changes, to make command decisions based on these modified perceptions of the situation, to take account of constraints imposed by resources, rules of engagement, and higher authority, and to prepare and issue directives to the FORCES. The FORCES, in turn, take actions that further change the COMBAT SITUATION.

Only the INFORMATION/COMMAND/ACTION loop of BLUE in Fig. 1 will be considered in detail in order to simplify the analysis and to make the problem more manageable. It is important to keep in mind, however, that this simplification neglects the very important aspects of the simultaneous counterpart RED_3 process, as well as the potential of each side for disrupting the C^3 capabilities of the other.

Figure 2 shows the INFORMATION/COMMAND/ACTION loop of one side in greater detail. The loop consists of several major segments, each with a detailed internal structure.

The first major segment is the INFORMATION segment. Its purpose is to gather, transmit, and merge data concerning the COMBAT SITUATION, and to present it to the responsible decision maker. The INFORMATION segment consists of a network of sensors (S), transmission links (T), fusion centers (F), and modes of data display and presentation (P). The network shown is only an arbitrary example, since fusion of sensor data can take place at any number of locations, resulting in a variety of network topologies.

Information, in the technical engineering sense, is the unifying concept of the INFORMATION segment. Information about the COMBAT SITUATION is necessarily modified and decreased by the actions of sensors, transmission links, fusion centers and presentation devices.

- Sensors sample certain characteristics of the COMBAT SITUATION in a limited geographical area, with finite resolution and added noise. Thus each sensor captures only a small fraction of the information inherent in the COMBAT SITUATION.

- Transmission links are subject to noise, outages and delays. These factors cause the sensor data to be late and subject to additional errors, both of which degrade the information content of the received data.

- Fusion centers filter, merge, and reconcile data from several sensors. Fusion can increase the information content when data from complementary sensors are merged. However, it can also decrease the information content by filtering and rejecting data and by introducing errors and delays. Fusion centers may also dissociate the true time sequence of the data stream.

- Presentation for a decision maker often further reduces the information content by compressing data into a format that can be readily assimilated by the decision maker. If this is not done there is a significant risk of overloading the decision-maker.

The net effect of these factors is to provide data to the decision maker at an information rate that is markedly less than the information rate inherent in the changing COMBAT SITUATION. The picture upon which tactical decisions must be made is always incomplete, usually late, perhaps out of sequence, and often erroneous.

The information-transforming processes that occur in the INFORMATION segment are physical processes that can be studied by scientific and engineering methods. Although the analysis is by no means simple, it does use familiar concepts.

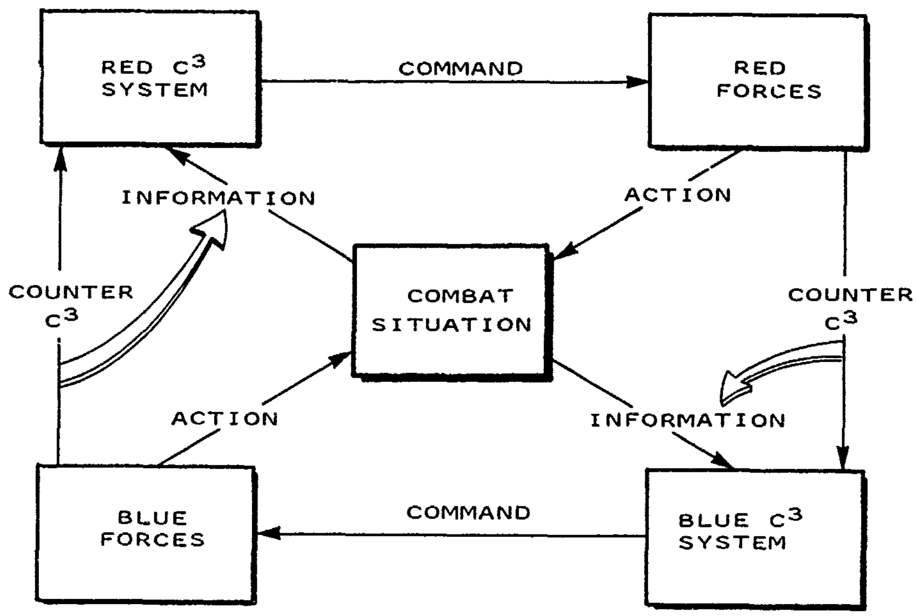


FIG. 1 REPRESENTATION OF WARFARE AS A PROCESS

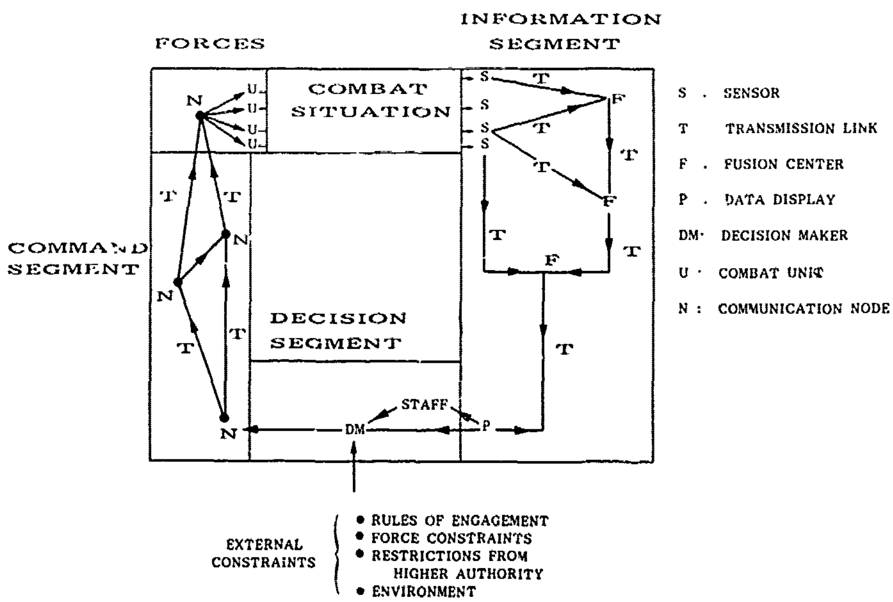


FIG. 2 REPRESENTATION OF THE COMBAT PROCESS: DETAIL OF THE BLUE LOOP

The sensors in an information network can be characterized by area coverage, bandwidth, resolution, data rate, signal-to-noise ratio (S/N); the data links can be characterized by channel capacities, error probabilities, time delays and statistics of outages; fusion centres can be characterized by data throughput capacities, filter rates, error rates, and time delays; and presentation devices can be characterized by data compression and data rates. The constituent elements can be linked and analyzed by stochastic network models.

It is thus possible in principle to provide a characterization of the quantity and quality of data that reaches a decision maker through an arbitrary network configuration.

The next major segment of the INFORMATION/COMMAND/ACTION loop is the DECISION segment. This normally involves one or more human decision makers. In simple loops at low levels of the command hierarchy, one human with limited resources under his control can perceive his input data directly, make intuitive decisions, and execute his decisions promptly. A fighter pilot is a good example of this level of complexity.

At the levels of greater relevance to ASW, the process is more complex, however. The decision maker will be surrounded by a staff, each of whom may review the input data and provide specialist advice. Consequently, the decision maker is presented with both the input data itself and verbal interpretation and commentary from his staff. He must weigh these inputs against a set of known constraints: limited resources, rules of engagement, environmental factors, guidance from higher authority, and the prerogatives of cooperating commanders. A decision is then made, formulated as a directive to the forces under his command, and transmitted to those forces.

The decision may not always result in a direct command to subordinate combat forces. Two common examples of decisions that may delay action are:

a) Deferring any form of decision until more information is available. This may involve simply waiting until more information accumulates in the normal course of events, or it may involve specific actions to obtain more information.

b) Requesting additional forces from higher authority or from cooperating commanders.

Information, in the technical sense, is also a consideration in the DECISION segment. However, it is neither the sole unifying concept, nor the dominating factor. The dominating consideration is the inescapable presence of human decision-makers - the so called "man in the loop". Any study of this DECISION segment must take full account of the capabilities for information assimilation and for decision-making of both individual humans and structured organizations.

Unlike the INFORMATION segment, the DECISION segment cannot be studied by generally accepted scientific and engineering methods. The concepts are ill-defined and controversial, and the relevance of formal analytical models is doubtful. The dominance of the man in the loop implies that different and more highly speculative methods are needed to analyse this part of the command and control process.

Nonetheless, some basic factors are known about human information processing. Humans are known to have a fundamental limit on the rate at which they can process information and make decisions. If that data rate is exceeded, humans engage in various adaptive strategies to cope with the information overload, all of which results in a reduction of the effective information rate. Prolonged overload conditions result in increased errors and faulty decisions. Structured organizations of humans respond to information overload in much the same way as individuals do. However, overload is believed to occur in organizations at lower information rates.

In addition, many humans react badly to the absence of information. If the data rate is too low, even for legitimate reasons, decision makers may intervene in the normal reporting process. Repetition of old reports or assurances that the situation remains unchanged may be solicited.

Another important characteristic of human decision-making is the predisposition toward a particular belief. Thus, a small amount of data that supports a prior belief may be given greater credibility than a large amount of data that contradicts it.

The practical consequences of these factors are that the DECISION segment of the loop shares some important characteristics with the INFORMATION segment: it introduces further delays, it filters the data quite substantially, and it can introduce additional errors. The decision maker thus acts on a very small fraction of the information that is inherent in the COMBAT SITUATION. From an analytical viewpoint, the drawback is that the processes in the DECISION segment cannot be studied quantitatively by generally accepted methods as can those in the INFORMATION segment.

The COMMAND segment of the loop formalizes the commander's decisions as directives to the FORCES. The directives are then transmitted to the FORCES by one or more communication links. The processes in this segment of the loop are relatively easy to describe and analyse. The key factors are time delays introduced in preparing and transmitting signals, circuit outages and overloads, and errors introduced in transmission. These can be analysed by standard engineering methods.

Since the COMMAND segment and the INFORMATION segment often use the same communication system, the loads caused by one segment can cause time delays in the other segment. In practical situations, it is usually the large volume of communications in the INFORMATION segment that causes delays in the COMMAND segment, not vice versa.

The loop is completed by the ACTION segment that involves the interactions between the FORCES and the enemy. This segment is, of course, enormously complex, and has been the principal object of the study of combat, both empirically and through analytical methods. However, this segment is outside the realm of C^3 proper and will not be discussed further in this paper.

Nonetheless, further errors can be introduced here by the misinterpretation of directives. In a multinational environment there are possibilities for misunderstanding the nuances of English. There are also substantial possibilities for misinterpretation of the latitude of actions allowed or required by loosely worded directives. The main importance of the ACTION segment in the present context is that it is the mechanism that changes the COMBAT SITUATION, thus necessitating the continuous flow of information through the C^3 system.

MEASURES OF EFFECTIVENESS OF C^3

Command, control, and communication (C^3) has no independent purpose. It is always part of a total combat system, and its purpose should be viewed in that context. In general terms, the purpose of C^3 is to provide for fully effective application of military force through correct targeting, timing, and coordination of force elements.

Currently fashion describes C^3 as a "force multiplier", implying that good C3 can enable military forces to perform beyond their normal capabilities. This report adopts the opposite point of view. If anything, poor C^3 is a "force divider." Perfect C^3 merely enables forces to perform at their expected levels, whereas less effective C^3 degrades force performance, often disastrously. Consequently, measures of effectiveness of C^3 should not be sought in the C^3 system itself, but instead, in the performance of the combat forces it supports.

While this view is correct in principle, it is extremely difficult to follow in practice. There are two principal reasons for this difficulty. First, C^3 and combat activities are intimately intertwined. It is thus nearly impossible to separate the effects of C^3 from the effects of tactics and execution. This is true both in the empirical study of real operations and in the analysis of combat models. Second, because humans are an integral part of the total C^3 process, it is also nearly impossible to separate the effects of human decisions from those of the inanimate parts of the C^3 system. As history constantly reminds us, commanders can make brilliant decisions on minimal information or they can blunder badly when they have ample information to support their decisions.

For these reasons, the ideal goal of measuring C^3 effectiveness through enhanced combat performance is often abandoned, and certain proxy measures of effectiveness that pertain solely to the isolated C^3 system are used instead. That is the general approach that will be used in this report, albeit reluctantly. The particular viewpoint adopted here is that of "demand-response." According to this viewpoint, combat actions create an added demand for C^3 services. The primary demand is for reaction by combat forces that must be directed and coordinated by command decisions. This, in turn, implies a secondary demand for information flow to support those decisions. C^3 systems are then judged by their capabilities to respond to a particular demand. The response is normally measured by the timeliness and quality of the information that is tailored to the needs of the decision-maker.

This approach has both advantages and disadvantages. The principal advantage is that it provides unique insights into the interactions between demand and response. These insights are lacking in other approaches that concentrate only on information flow.

One major disadvantage is that the approach is specific to a given situation. The demand for C^3 services is created by the operational requirements, which can vary widely from mission to mission. The C^3 demand in AAW is totally different from that in ASW; the C^3 demand in the ASW defence of a carrier battle group is very different from that in independent ASW operations by maritime patrol aircraft. This specificity makes the analysis of each mission easier, but it hampers the development of general results.

Another disadvantage is that the demand-response approach is much better at comparative analyses than at absolute analyses. When the C^3 demand has been established for a particular mission, it is relatively easy to compare the responses of two different C^3 systems and to determine which is superior to the other. It is much more difficult to determine with confidence whether one or both systems are adequate for the task. This is because the threshold for sufficiency is hard to define exactly if the influence of C^3 on operational performance is neglected.

Despite those drawbacks, the demand-response viewpoint is a powerful method for doing C^3 analyses and provides a very useful tool for the improvement of C^3 in exercises and real world operations.

THE IMPROVEMENT OF C^3

Because C^3 is a vital part of combat capability, military organizations strive to improve C^3 as much as possible as one means of enhancing their overall operational performance. In the broadest sense, two categories of improvement can be sought. Long term improvements derive principally from research and development leading to better systems for collecting, processing, presenting, and disseminating information. These are normally under the direction of research and development (R&D) authorities in the relevant nations and services. Shorter term improvements derive principally from changes in procedures, tactics, training, and command structures. These factors are normally under the control of operational commanders.

The NATO alliance presents a unique problem with regard to the first category. Since R&D is the responsibility of the nations and is almost always done for national purposes, NATO can do little to influence the process directly. There is value, however, in making unique NATO requirements known through the appropriate information exchange groups, so that national authorities can be aware of them at least. For this purpose, a good quantitative understanding of NATO's maritime C^3 needs, as well as quantitative documentation of current C^3 performance is indispensable.

Regarding the second category, NATO operational commanders have much greater control over the factors that affect C^3, and are in a position to take appropriate steps for improving performance.

There are a number of factors that oppose the improvement of C^3 and place limits on the degree to which improvements can be made. These opposing factors can be grouped into three categories.

a. The Enemy: Like combat itself, the C^3 that supports combat exists in a competitive environment. Not all aspects of C^3 performance are controlled by one's own forces, and they are not always subject to unilateral improvement. The enemy has particularly strong influence on the demand for C^3 services. The demand is partly controlled by the tempo of operations which depends as much on the enemy as on own forces. This is particularly true for situations in which the enemy is in an offensive posture and own forces are in a defensive posture. The enemy can then choose the number, location, and timing cf attacks. In this way it can exert strong influence on the tempo of operations and the demand for own force C^3. In addition, the enemy can limit the performance of own force C^3 more directly by the use of deceptive tactics, decoys, and jamming, all of which decrease the flow of information to own force decision-makers.

b. Nature: The laws of nature and the characteristics of the operating environment impose fundamental limits on the performance of C^3 systems. Some of these are well understood and widely recognized; others are poorly understood as natural phenomena and scarcely recognized as limiting factors in C^3 performance. Further, some are definite, deterministic phenomena that can be described and predicted accurately by the laws of physics; others are random phenomena that can be described and predicted only in a statistical sense. Examples of these limiting factors include bandwidths and coverage patterns of sensors, data rates of communication links, environmental noise affecting sensors and communication links, processing capacities of filter centres, random failures of system components, time delays imposed by human operators, and information processing capacity of individual humans and structured human organizations.

c. Cost: Absolute monetary cost is well recognised as a limiting factor on the improvement of C^3 performance. There are other more subtle issues related to costs that should be recognized as well. In the broadest sense, the cost constraint applies not to C^3 systems alone but to the combination of C^3 and combat systems. The broad objective is to obtain the greatest combat effectiveness for a fixed budget. Although improvements in C^3 can improve the combat effectiveness, there is a point beyond which it is more cost-effective to procure additional combat systems than to continue to improve the supporting C^3.

These arguments may seem moot to operational commanders who have no control over R&D or procurement, and who must make do with available resources. However, it should be recognized that the same argument applies to non-monetary operational costs as well. The improvement of C^3 performance by procedural methods may require operational resources that could also be used more directly in combat. In such cases the commander must determine whether the goals of effective combat capability are better served by devoting resources and effort to improving C^3 or to direct combat missions. This judgment is not always easy to make, but it is important to recognize that such a trade-off is implicit in the constraint on operational resources, and that uncritical pursuit of C^3 improvements may not be the best way to achieve the broader operational goals.

Tables 1 and 2 present some of these considerations in a systematic format. Although many of the entries in these tables are self-explanatory some further comments are necessary.

- Tempo of operations (Table 1) can affect the demand for C^3 services in several ways, some of which involve own force operations only, and others of which involve the interactions between own forces and the enemy. With specific reference to NATO ASW, it is often noted that because of the number of area, sub-area, and seagoing ASW commands, extensive coordination is required for large scale ASW operations. Forces must be requested for ASW search and surveillance and control must be transferred when area boundaries are crossed. This type of demand for C^3 services exists regardless of the actions of the enemy and increases with the tempo of own force operations.

  Interactions with enemy forces create another type of demand. Every detection of a submarine acts as a trigger event for a sequence of responsive actions and each responsive action requires some C^3 services. Many of these responses are taken from a standard repertoire, so that the C^3 demand is at least partly predictable. It is possible to think of each trigger event (e.g. submarine detection) as creating a demand "footprint" - a characteristic pattern of C^3 services that persists throughout an action sequence. The total demand is then governed by the rate of submarine detections which can be influenced by both own and enemy tempos of operation.

- Own command structure (Table 1) can have major effects on C^3 demand. The greater the number of separate commands involved in the structure relevant to an operation, the greater the amount of coordination and communication required. This is particularly evident in combined ASW operations in which own force ships, aircraft and submarines are subordinate to distinct and often widely separated commands. In the absence of standard procedures for transferring operational control of all relevant forces to the on-scene commander, a submarine prosecution thus creates a large demand for real time coordination among commands and their subordinate forces. Even in cases in which a commander is not directly involved in an operation, command prerogatives may require informing him, thus creating a demand that has little immediate operational relevance.

  From a technical viewpoint, experience has suggested that when N participants (commands or operational units) are involved in an operation, the C^3 demand is not proportional to N, but is some non-linear function of N (perhaps N^2 or some higher power). The precise mathematical form is not known and is not particularly important. What is important is that the demand grows more rapidly than the number of participants. Consequently, it can be controlled more easily by limiting the number of commands that must be involved in an operation.

- Own C^3 structure (Table 1). Occasionally technical limitations on communication will require the use of awkward C^3 structures that, in effect, increase the demand in some parts of the system. The difficulty that ships and aircraft have in communicating with submerged direct support submarines is a practical example.

- Own C^3 procedures (Table 1) have a very significant impact on C^3 demand. This is most evident in the area of record traffic communication, in which such factors as use (or abuse) of precedence, address indicator groups (AIGs), and standard reporting requirements create massive system overloads. The operationally relevant traffic is lost or delayed, due often to adherence to the letter but not the spirit of standing C^3 procedures. The recent successes of ad hoc traffic screening boards in exercises shows that this aspect of demand can be managed but at some cost. The longer term goal should be to control it permanently and routinely.

- Own tactical procedures (Table 1) naturally have strong influence on C^3 demand. However, this is not a fruitful area generally for seeking ways to reduce C^3 demand. Tactics must drive C^3, not vice versa; less effective tactics should never be adopted just because they require less C^3. Only in cases in which the effectiveness is roughly equivalent among alternative tactical procedures should the amount of C^3 demand be considered.

TABLE 1

FACTORS AFFECTING DEMAND FOR C^3 SERVICES

FACTOR	CONTROLLING INFLUENCES: ENEMY	NATURE OR ENVIRONMENT	OWN TECHNOLOGY	OWN OPERATIONS
¶ NUMBER				
- OF OWN UNITS				X
- OF ENEMY UNITS	X			
¶ TEMPO OF OPERATIONS	X			X
¶ OWN				
- COMMAND STRUCTURE				X
- C^3 STRUCTURE				X
- TACTICAL PROCEDURES				X
- C^3 PROCEDURES				X

° Fusion center filter rules (Table 2). The rules by which incoming data from sensors are filtered and merged can have important subsequent influences in the DECISION segment of the C^3 loop. The commander and staff can proceed more quickly to a decision if the incoming data stream is reduced to manageable proportions and tailored to the operational situation. Many commanders are reluctant to allow this, however, since it is viewed as an unwarranted delegation of command authority; they would prefer to deal with unfiltered data. As a consequence, staffs may have to do the filtering and fusion themselves to the detriment of their other duties.

The severity of the problem varies greatly with the type of warfare. Fortunately, in ASW the basic data rate is relatively low, and the need for prefiltering is less than in, say, air defence. Nonetheless it is an issue that should be considered by the operational commander in setting up his C^3 procedures.

In a multithreat environment, the demand created by other areas of warfare will be large and may interfere with the effective functioning of ASW C^3.

° Restrictions from higher authority (Table 2). When senior commanders do not delegate sufficient authority for their subordinates to conduct operations, the decision process of the subordinate is altered and delayed. He must consider whether or not to request a relaxation of these restrictions; if he wants relaxation he must actually seek and receive the necessary permission. Much of this can be avoided by a realistic degree of prior delegation or by command by exception.

TABLE 2

FACTORS AFFECTING THE RESPONSE OF C^3 SYSTEMS

FACTOR	CONTROLLING INFLUENCES: ENEMY	NATURE OR ENVIRONMENT	OWN TECHNOLOGY	OWN OPERATIONS
A. <u>INFORMATION SEGMENT</u>				
¶ SENSOR				
- DEPLOYMENT				X
- TECH. CHARACTERISTICS		X	X	
- NOISE		X		
- COUNTERMEASURES	X	X		
¶ COMMUNICATION				
- NETWORK STRUCTURE				X
- NETWORK CAPACITY		X	X	
- LINK OUTAGES		X		X
- DELAYS				X
- ERROR RATE		X	X	
- COUNTERMEASURES	X	X		
¶ FUSION CENTRE				
- CAPACITY		X	X	
- FILTER RULES				X
- TIME DELAYS				X
- ERRORS		X		
¶ DATA DISPLAY				
- DISPLAY RATE			X	
B. <u>DECISION SEGMENT</u>				
¶ HUMAN INFO/PROCESSING CAPACITY		X		
¶ STAFF STRUCTURE				X
¶ STAFF INFO/PROCESSING CAPACITY		X		
¶ RULES OF ENGAGEMENT				X
¶ RESTRICTIONS FROM HIGHER AUTHORITY				X
¶ AVAILABILITY OF FORCES				X
C. <u>COMMAND SEGMENT</u>				
¶ COMMUNICATION				
- NETWORK STRUCTURE				X
- NETWORK CAPACITY		X	X	
- LINK OUTAGES		X		X
- DELAYS				X
- ERROR RATE		X	X	
- COUNTERMEASURES	X	X		

Taken together, Tables 1 and 2 show several important factors that affect the balance between demand and response in C^3. The two tables also show significant differences. Table 1 indicates that demand for C^3 is controlled by the contending forces and not by environment or technology. Table 2 shows a different distribution of influences. Environment has a strong influence on many of the response factors and often imposes strict limits. Technology strives to bring system performance up to those limits. Although several of the response factors are influenced by own operations, the degrees of influence are often minor.

From the operator's viewpoint, he must take the enemy, the environment, and his own current technology as he finds them and do the best he can by changing the procedural and structural factors under his control. These tables suggest that the operator has a much greater chance of improving the overall C^3 process by decreasing the demand than by increasing the response. This runs counter to much conventional wisdom. Most studies of C^3 take the demand as an externally imposed goal, and then seek ways, usually involving technology, to meet the demand. Historically this has been an expensive and not very satisfactory approach. Each technological advancement in C^3 has been quickly saturated by demands for more and more information. The viewpoint here, that much of the demand is self-created and not always operationally relevant, offers a far more promising approach for bringing C^3 under control.

ROLE OF ANALYSIS IN THE IMPROVEMENT OF C^3

The previous section listed several factors that are under the control of own force operational commanders and that might be changed to bring about improvements in C^3 performance and, consequently, in operational effectiveness. Although the list is relatively short, the number of combinations of possible changes is still far too large to ever be tested in an exercise or operational environment. Thus, alternate means of evaluating possible improvements are needed. Operational experience provides one such means; analysis provides another.

Operational experience generally provides reliable guidelines for situations that are similar to those of the past. In those cases analysis can provide a complementary check on operational experience but may not contribute anything unique.

In situations that depart drastically from customary practice, experience is no longer a reliable guide; analysis is often the only means for exploring the consequences of such major changes.

Wide ranging variations can be investigated relatively quickly. Promising solutions can be identified for testing in exercises, and controversial, counter-intuitive findings can be isolated for more thorough study. In general, three categories of situations, each of which represents major departures from common experience, seem appropriate for analytical investigation. They are:

a. Major variations in numbers of forces and tempo of operations. Existing C^3 practices are generally satisfactory in small exercises involving a few forces in a limited geographic area. Experience has shown repeatedly, however, that these same procedures lead to unsatisfactory results in major naval exercises covering the whole Atlantic theater. The volume of traffic increases very quickly beyond the saturation point, large backlogs and long delays develop, and necessary operational traffic is not received in time to affect the conduct of operations. These are not the result of malevolent actions to hamper the exercise. It is the result of applying standard, approved and accepted procedures in an operating regime that is very different from that normally experienced. The procedures that work well with small numbers of forces and modest tempos of operation reach a breakdown point as the numbers and tempo increase. It is not possible to determine empirically where the saturation threshold occurs because small operations are well below it and major exercises are well above it. That is one issue that can be investigated analytically.

   A far more important set of issues to investigate analytically are the causes of the overload and the options for relieving it. Although traffic screening boards have worked well in some recent exercises, they are ad hoc measures, so their successful aspects need to be identified and used routinely. In this context it is especially important to recognize that the stresses placed on the C3 system in a real war would greatly exceed those experienced in the largest exercises. For that reason alone, a thorough understanding of the effects of very high stress levels is vital.

b. Major changes in command structure and organization. Such changes, never easy to implement, certainly cannot be tested in exercises. Moreover because of political resistance to any structural changes, they can never be undertaken lightly or without strong justification. Analytical methods can be used to explore in a benign atmosphere the consequences of structural changes and to determine whether any justification exists.

c. Multiple small changes in several factors. While operational experience can usually predict the effects of small changes implemented singly, that sort of intuition is less applicable when several changes occur at once in diverse parts of a system. In this situation analytical methods can be a very useful adjunct to operational experience.

ANALYTICAL METHODS AND TOOLS

Although the details of C^3 analysis can become enormously complex, the underlying philosophy is quite simple.

The principal goal is to be able to predict with reasonable accuracy the C^3 demand and response in circumstances far removed from prior experience. To accomplish this, one must first study demand and response in familiar circumstances and be able to replicate the observed performance analytically. Only then is there any justification for trying to extrapolate to new conditions.

The principal mechanism for doing the analysis is a set of loosely connected models of different types. The earlier discussion in this paper portrayed the C^3 process as a continuous loop consisting of several connected segments. Because the natures of these segments are fundamentally different, quite different models are needed for each. An all-encompassing model of the whole C^3 loop would be neither feasible nor useful. It is far more instructive to consider the details of each segment separately.

The set of useful models will include:

° A subset of demand models that relate tempo of operations to demand for C^3 services. These should be simple, descriptive, empirical models that require little more than hand calculations. For the ASW case, it is necessary to distinguish between steady state demands (e.g. routine search and surveillance operations) and event-driven demands (e.g. submarine prosecutions or major changes in defensive posture).

° A stochastic network model of the INFORMATION segment of the C^3 loop. Such a model would be a mathematical, computer-based model that represents the dynamics of information flow. It would be driven by the demand model, and would incorporate the effect of errors, delays, and outages in the links and nodes of the INFORMATION segment.

° One or more heuristic models for the DECISION segment of the C^3 loop. It was pointed out earlier that this is the least understood part of the process, so all models must be regarded as speculative. Various options that are available for investigation include artificial intelligence (expert systems), man-in-the-loop simulation models, and war gaming.

- A stochastic network model for the COMMAND segment. As in the INFORMATION segment, this model would incorporate the dynamic effects of errors, delays, and outages in the transmission of commands to operational forces.

- A combat simulation for the application of forces. This would respond in a limited way to command inputs and would modify the COMBAT SITUATION for the beginning of the next cycle around the C^3 loop.

These various models can differ quite significantly both in their degree of difficulty and in their importance for understanding and improving the C^3 process. Table 3 illustrates this. The judgements in Table 3 form the basis for establishing analysis priorities. Modelling of the demand and the INFORMATION segment are both highly important and moderately difficult. Consequently they should be attempted first. Modelling of the DECISION segment is both very difficult and very important and should receive next priority. The other two are generally less important and can be neglected initially.

TABLE 3

RELATIVE DIFFICULTY AND IMPORTANCE OF MODELS

MODEL FAMILY/TYPE	DIFFICULTY	IMPORTANCE
¶ DEMAND	Moderate	High
¶ STOCHASTIC NETWORK		
- INFORMATION segment	Moderate	High
- COMMAND segment	Moderate	Low*
¶ DECISION segment	High	High
¶ COMBAT SIMULATION	High	Low*

*For initial study but not in the real world.

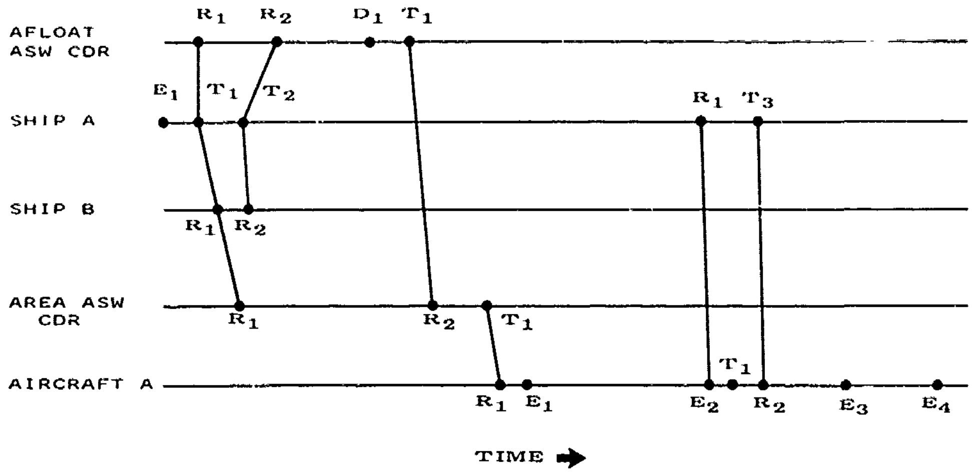
Some basic factors are common to all types of modelling, and these must be firmly grounded in the empirical reality of the system being modeled. Broadly speaking, these general factors are the structure of the system, the dynamic characteristics of the system, and the body of empirical data that serves as both inputs and structural parameters for the models. Of these, the first two can be based on the operational knowledge and technical expertise in C^3. The third category is vitally dependent on data from naval exercises to ensure realism.

This last factor must be regarded as the single most important aspect of any analytical approach to C^3: input data must be realistic, representative of current operational practices, appropriately matched to the models, and sufficiently abundant to ensure statistical reliability. For this reason, a carefully planned programme for collecting quantitative data during a series of ASW exercises should be pursued. The second part of this report lays the ground work for such a programme.

Irrespective of the details of the models, one analytical tool is extremely useful in the analysis of C^3. This is the operational sequence diagram, or OSD, of which Fig. 3 is a simplified example. The OSD is a clear and simple way of organizing the information that is most relevant to C^3 analysis. It can be used to present the procedures specified in tactical publications to show how operations ideally should take place; it can be used to organize and present real-world data to demonstrate actual operations; and it can be used to compare the ideal operations with the real operations, and, thereby, to identify the critical differences.

Figure 3 shows, the OSD displays time along the horizontal axis and the participants of an operation along the vertical axis. For each participant, three categories of events are shown as functions of time: actions, decisions, and communications. This format is a convenient repository for the primary operational data. It also allows quick calculation of derivative quantities: time delays in communication; times between receipt of information and decisions; time between decisions and action; and time to complete actions. In addition, it facilitates discussion of various "what if" questions, i.e., what if the chain of command had been different? what if message routing had been different? what if a decision had been delayed until further information became available?

OSDs should play a major role in the planning, observation, and analysis of major ASW exercises. The next part of this report elaborates this point.



AFLOAT ASW CDR

- R_1 : Receive initial contact report
- R_2 : Receive request for localization assistance
- D_1 : Decide to use aircraft
- T_1 : Request aircraft from Area Cdr

SHIP A

- E_1 : Long range submarine contact
- T_1 Report contact
- T_2 : Request assistance in localization
- R_1 Receive joining message from aircraft
- T_3 : Send target data to aircraft

SHIP B

- R_1 Receive initial contact report
- R_2 : Receive information request for localization assistance

AREA ASW CDR

- R_1 : Receive initial contact report
- R_2 : Receive request for aircraft services
- T_1 : Direct aircraft to report to ship A DIRLAUTH

AIRCRAFT A

- R_1 . Receive direction to report to ship A
- E_1 Begin transit
- E_2 : Arrive on scene
- T_1 : Send joining message to Ship A
- R_2 Receive target data from Ship A

FIG. 3 SAMPLE OPERATIONAL SEQUENCE DIAGRAM

PART II

APPLICATIONS TO MARITIME EXERCISES

In the first part of this report it was asserted that empirical data from exercises are a vital component of the analysis of command and control. This part of the report lays out a set of general requirements for the collection and analysis of such data. The plan set forth here is both general and idealized. It is general in the sense that not every item will be relevant to every exercise. It is ideal in the sense that it specifies far more detail than can normally be acquired with the limited resources available for the observation, reconstruction and analysis of NATO naval exercises. Thus it represents a source of requirements from which items can be selected for consideration in specific exercises.

The menu does not provide a carte blanche, however. Some items are simply more important than others and therefore should receive priority attention. The subsequent discussion provides some indication of priorities from the analytical viewpoint.

It is also important to distinguish among work to be done before the exercise in preparation for the data collection, the observation and data collection during the exercise itself, and the reconstruction and data analyses after the exercise. The key activities for each of these phases are identified below.

It was previously argued that the most important aspects in understanding the overall C3 process are (1) the demand; (2) the response of the INFORMATION segment; and (3) the response of the DECISION segment. Accordingly, these three elements are given high priorities in the subsequent plan.

MEASUREMENT OF C^3 DEMAND

Demand will, of course, vary according to the situation, but the basic goals of the data collection effort are to:

(1) To identify a small number of qualitatively different situations that are representative of the broad range of ASW operations;

(2) To identify a factor that is a reliable indicator of tempo of operations for each situation;

(3) To measure the C^3 demand for those tempos of operations that occur in the exercise; and

(4) To extrapolate the demand as appropriate to other tempos of operation.

Table 4 lists the situations that seem most .mportant for the measurement of demand. Of the seven different situations defined in Table 4, submarine detection is the most important to understand initially although it may turn out that other situations actually dominate the C^3 demand. Therefore each situation should be observed in at least some exercises.

Table 5 lists the steps that need to be accomplished before an exercise to assist in the measurement of C^3 demand. Some are steps that must be taken early in the planning stage; others can be accomplished just before the exercise.

Table 6 shows what data should be collected during the exercise.

Table 7 lists the major steps of the post-exercise reconstruction and analysis.

It should be noted that non-ASW traffic may dominate the commom user circuits. That traffic is of course vitally important in determining the overall system response and needs to be studied in its own right. Here, however, the immediate emphasis is on the ASW C^3 demand and its relationship to the tempo of ASW operations.

TABLE 4

SITUATIONS FOR MEASURING C^3 DEMAND

A. Steady State Demand
1. Area Search and Surveillance
2. Moving Point of Intended Movement (PIM): protection of High Value Unit (HVU) in local area.
B. Event-driven demand
1. Event initiated by own forces
a. Major force movement across area boundaries
b. Establishment/Reconfiguration of Defended Lane
c. Establishment/Reconfiguration of Fixed PIM defensive area
2. Event initiated by interaction with enemy
a. Submarine detection
b. Flaming datum

TABLE 5

PRE-EXERCISE ACTIVITIES RELATED TO THE MEASUREMENT OF C^3 DEMAND

1. Select from Table 4 those specific operational situations to be evaluated.

2. If appropriate, select a time frame within the exercise when demand evaluation will be done. This will be governed in part by the phasing of the exercise activity. It may also be governed by a desire to avoid atypical circumstances early in an exercise, when participants are not fully practiced in the operational procedures. For the measurement of steady state demand, the duration of the time frame can be somewhat arbitrary. For the measurement of event-driven demand, the time frame must begin with the designated event, and continue until the operational consequences of the event have been completed.

3. Identify all likely participants on the basis of the operational situation and the time frame selected. The participants should include the most senior command with direct operational responsibility for the situation, and should extend down to the unit level with responsibility for carrying out the operations.

4. Prepare a pre-exercise diagram of command relationship of all participants identified in 3.

5. Prepare a pre-exercise communications connectivity diagram showing all planned communication links among the participants identified in 3. Circuit types, data rates and any special characteristics or restrictions (e.g. line of sight) should be noted.

6. Using standing procedures and exercise OpOrders, prepare notional operational sequence diagrams for the selected situations, showing actions, decisions, and C^3 as specified "by the book".

TABLE 6

DATA COLLECTION REQUIREMENTS RELATED TO THE MEASUREMENT OF C^3 DEMAND

1. For the time frames identified in Table 5, item 2, collect copies of all record traffic on all circuits among the identified participants.

2. For the identified time frames, make tape recordings of all voice circuits among the identified participants.

3. Ensure that enough operational data is collected to infer the "tempo of operations". This will normally be done routinely as part of the exercise records. For event-driven demand, the occurrence of one event specifies the tempo. For steady state demand, some proxy measure, such as rate of area searched, will suffice as a measure of tempo.

TABLE 7

POST EXERCISE ANALYSIS RELATED TO THE MEASUREMENT OF C^3 DEMAND

1. Revise the diagram of command relationships, if necessary, based on actual exercise experience.

2. Revise the diagram of communications connectivity, if necessary, based on actual exercise experience.

3 Transcribe tape recordings of voice circuits.

4. Select ASW record traffic out of total traffic occurring on non-dedicated circuits.

5. Select ASW-related voice communications occurring on non-dedicated circuits.

6. Using results of 4 and 5 above, prepare revised operational sequence diagrams that display actions and C^3 as actually occurring.

7. Compare pre-exercise and post-exercise operational sequence diagrams.

8. Compute the loading on each circuit as a function of time, either continuously in steady state, or dependant on elapsed time from the trigger event.

9. Aggregate the results of 8 to produce demand "footprints" to and from each participant as a function of time.

10. If the tempo of steady state operations varied during the exercise, relate the C^3 demand to the tempos of operation.

MEASUREMENT OF PERFORMANCE FACTORS IN THE INFORMATION SEGMENT

This is a second major element to be considered in the analysis of C^3 performance. The factors that are important in measuring the response of the INFORMATION segment of the C^3 loop are the time delays, errors, and omissions that are introduced in that segment, and the causes of these reductions of information. Consequently, one must describe the structure of the INFORMATION segment, the performance of each of its elements, and the performance of the segment as a whole. Technical parameters are important for the measurement of the performance of the constituent elements, whereas the comparison of information input with output is important for the measurement of performance of the whole segment.

The specific structure of an INFORMATION segment will vary with the operational situation. Thus it is necessary to specify first the situations to be analysed. The list in Table 4 will serve as well for the performance analysis of the INFORMATION segment as for the measurement of C^3 demand. Although it is not absolutely necessary that the same situations be selected in each case, the amount of work involved and the number of observers required is much reduced if the same situations are used. It is particularly important that submarine detection and prosecution be one of the situations considered.

Table 8 lists the steps to be accomplished before the exercise. Table 9 lists the requirements for data collection during the exercise. Table 10 lists the steps of the post-exercise reconstruction and analysis.

TABLE 8

PRE-EXERCISE ACTIVITIES RELATED TO THE ANALYSIS OF PERFORMANCE OF THE INFORMATION SEGMENT

1. Select from Table 4 the specific operational situations to be evaluated.

2. Select the time frames during which evaluation will be accomplished.

3. For the operational situations and time frames thus selected, identify the likely principal operational decision maker. This should be the ASW commander who will make substantive decisions about the conduct of operations. The mere execution of standing procedures should not be construed to constitute substantive decisions except in cases where positive decisions are required as part of those procedures.

4. For the principal decision maker identified in 3, prepare a pre-exercise diagram of his INFORMATION segment. This segment will include:

   a. all subordinate platforms that have an information-gathering capability;

   b. all external data sources (not subordinate) that provide current operational information;

   c. the sensors associated with these various platforms and sources;

   d. all data fusion centers (if any) separate from the command center of the decision maker himself;

   e. the communications links connecting all subordinate platform, external data sources, fusion centers, and the decision maker's command center.

   f. Data presentation and display devices in the decision maker's command center.

5. Assemble a list of available technical characteristics of the sensors, data links, fusion centers, and display devices described in 4.

TABLE 9

DATA COLLECTION REQUIREMENTS RELATED TO THE ANALYSIS OF PERFORMANCE OF INFORMATION SEGMENT

1. Operating logs for all relevant sensors, showing times in operation, operating modes, system failures, repairs, etc.

2. Contact logs for all sensors showing both valid and false contacts.

3. Hard copy of all contact reports sent by message. It is important that multiple copies be obtained at each receiving node in the network. These should be stamped with time of receipt at each node.

4. Tape recordings of voice circuits for those cases in which contact reports are not sent by message. The tapes should have time references.

5. Operating logs for all communications circuits, showing outages and circuit quality as a function of time.

6. If any fusion centers are in operation, other than the command center of the designated decision maker, hard copy of all outputs from those fusion centers should be obtained. As in the case of contact reports, multiple copies should be obtained at each forward node and stamped with time of receipt.

7. Records of the data presentation device in the command center of the designated decision maker. If an afloat ASW commander is using NTDS as his principal display, then data extraction from NTDS is required. If manual displays are the principal mode, either afloat or ashore, periodic photographs of the displays are required.

TABLE 10

POST-EXERCISE ANALYSIS RELATED TO THE ANALYSIS OF PERFORMANCE OF THE INFORMATION SEGMENT

1. On the basis of the track reconstruction, develop a true picture of exercise participants during the time frame under consideration. Estimate the information content of the true picture, as a function of time, using standard information theoretical measures.

2. On the basis of the sensor contacts, both valid and false, develop a picture of the exercise as perceived at the sensor level. Estimate the information content of the sensor level picture as a function of time, taking account of both omissions (missed contacts) and errors (false contacts).

3. Compile statistics on circuit outages.

4. Compile statistics on time delays of contact reports, by circuit and by destination.

5. If intermediate level fusion centers are in use, compile the following data on fusion center performance.

   a. Information content of the input as a function of time.

   b. Information content of the output as a function of time.

   c. Time delays, errors, and omissions in fusion center processing.

6. Compile statistics on time delays of fusion center reports, by circuit and by destination.

7. If fusion occurs only in the command center of the designated decision maker, compile the following data on the fusion process in the command center.

   a. Information content of the input as a function of time,

   b. Time delays, errors, and omissions in transforming data inputs into presentations for the decision maker.

   c. Information content of the principal display as a function of time.

8. Compare the estimates of the information contents of:

   a. True Picture
   b. Sensor Level Picture
   c. Input to Fusion Center
   d. Output of Fusion Center
   e. Input to Command Center
   f. Presentation to Decision Maker

MEASUREMENT OF PERFORMANCE FACTORS IN THE DECISION SEGMENT

This is the third and by far the most difficult element in the analysis of C^3 performance. The conceptual difficulties have been discussed in the first part of this paper. There are also formidable practical difficulties in the collection of useful data because many of the significant events are occurring in the minds of the participants.

The key participant is the designated decision-maker, the ASW commander or his designated subordinate (usually his operations officer). However, other staff officers also play important roles and their mental processes may be of interest as well.

Any serious data collection effort must have the fullest cooperation and support of the decision-maker and his staff. Without that support nothing useful can be done nor should be attempted. Willing cooperation is not enough, however, since all key participants are very busy during an operation. Thus, their cooperation must be abetted by the most efficient techniques for capturing the important data.

In an analytical approach to C^3, the quality of decision is not at issue. That is a matter of military judgment not analysis. Matters that are at issue are:

- when a decision was made,
- what information was available at the time to support the decision,
- what information was actually used by the decision maker, and
- what constraints were taken into account by the decision maker.

The first two points are matters of fact and can, in principle, be observed by independent assessors; the latter two points are subjective judgments that can come only from the decision maker himself.

A number of techniques are available to elicit such judgments from cooperating decision makers. Some people have proven adept at using small pocket dictaphones to record their thought processes even during fast-paced operations. Others prefer to be interviewed by independent assessors during lulls in the action. These methods may be supplemented by formal command narratives and by post-exercise debriefings.

Tables 11 to 13 give particulars. In the application of the procedures in these tables, it is important to note that, since the DECISION segment is a logical continuation of the INFORMATION segment, the same situations and time frames should be used for both in the exercises. This simplifies data collection as well as provides a more thorough examination of the C3 process in each operational situation.

TABLE 11

PRE-EXERCISE ACTIVITIES RELATED TO THE ANALYSIS OF PERFORMANCE OF THE DECISION SEGMENT

1. Select the same operational situations, time frames, and decision-makers as used in studying the INFORMATION segment (Table 8).
2. Brief the selected decision-makers on the goals of the data collection effort, and seek their approval and cooperation in the collection of subjective data.
3. Prepare sketches and diagrams of the decision-maker's command center, showing layout, information inputs, data displays, normal work areas, manning, etc.
4. Acquire any special data collection devices, eg. dictaphones, polaroid cameras.

TABLE 12

DATA COLLECTION REQUIREMENTS RELATED TO THE ANALYSIS OF PERFORMANCE OF THE DECISION SEGMENT

1. Permanent records of data displayed for the decision maker. This may take the form of data extract from NTDS displays, or periodic photographs of manual displays.
2. Observer and/or command narrative of activities by staff in interpreting, analysing, or supplementing the principal displays for the decision maker. This should emphasize any activities that in any way modify the direct perception of the tactical data by the principal decision maker.
3. Logs of decisions taken, and outgoing hard copy communications of those decisions.
4. Real time dictation, interview, or commanders narrative, giving background of the decisions, with special emphasis on key items of information that led to or supported the decisions.

TABLE 13

POST-EXERCISE ANALYSIS RELATED TO THE PERFORMANCE OF THE DECISION SEGMENT

1. From the decision maker's narrative, determine for each tactical decision the relevant items of information. Determine the time delay between the availability of those items of information and the decision itself. Isolate any cases in which decisions were delayed by obvious physical constraints. For the remaining cases, examine separately items for which

   a. the decision maker dealt directly with tactical data,

   b. staff interpretation was inserted between the tactical data and the decision maker.

2. Compile statistics on the amounts of information used in formulating decisions; compare with amount actually displayed.

3. Compare the items of information used for decisions with the information content of the true tactical situation. Note particularly any items of erroneous data that were used in decision-making.

4. Compile statistics on the time delays between the decision and the communications of those decisions to subordinates.

5. Since this area may contain unexpected findings that cannot be anticipated, a critical compilation of lessons learned from the decision maker's narratives will be most useful.

SUMMARY

This part of the paper has set some broad objectives for planning, observing and analyzing NATO ASW exercises for the purpose of developing an analytical basis for C^3 studies. The requirements exceed the resources that would normally be available for any single exercise; therefore specific data collection and analysis tasks for specific exercises will be selected from those listed here. Over a series of exercises, coordinated choices of objectives may be able to provide a reasonably thorough coverage of the entire C^3 process.

The choice of data collection and analysis tasks for a particular exercise will depend on the overall structure and objectives of the exercise, the availability of assessors and analysts, the availability of special data recording facilities, and many other administrative constraints. In matching the objectives with the available resources, two principles should be respected.

- A thorough examination of a limited part of the C^3 process is much more valuable than a superficial examination of the entire process.

- Generally, transient, event-driven processes are more instructive than steady state processes. Consequently, they should have higher priority, in spite of the greater difficulties involved in the data collection and analysis. Notwithstanding, the steady state provides the background against which event-driven processes must be evaluated.

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