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COMMAND, CONTROL AND COMMUNICATIONS

Basic concepts and characteristics*

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One of the notable features of the literature published on military topics in recent years has been the growth of interest shown in command, control and communications. The aim of this article is to provide the reader with a general overview of this subject, and to give him a clear picture of all the different aspects that are entailed in it.

The increasing interest in topics relating to command and control has been reflected in the proliferation of terms concerning the subject. The most common of these are C^2 (command and control) C^3 (command, control and communications), and $C^3 I$ (command, control, communications and intelligence, especially of an operational kind).[1]

Part of the attraction of C^3 is that it is 'all things to all men', as one writer puts it.[2] Thus, once one gets beyond vague definitions such as 'Command and Control is running the show',[3] there is sometimes little similarity in the way individual writers use the concepts of C^2 and C^3. To gain some initial clarity in this area, three different fields which are commonly referred to under the headings of C^2 and C^3 can be distinguished — firstly, the authority *structure* through which command and control are exercised, secondly, the *process* of command and control, comprising such activities as planning and decision-making, and the *technology* which is used to aid those involved in the command and control process.

In addition, two different levels of C^2 and C^3 can be distinguished in the military sphere — namely the strategic and the tactical. Strategic C^2 and C^3 relate to the overall organisation of a military force in 'distributing and applying military means to fulfil policy',[4] to use Liddell Hart's words. Tactical C^2 and C^3 on the other hand are concerned with forces *near or in contact with opposing forces*[5]. C^2 and C^3 naturally vary in nature and requirements depending on the level at which they are being conducted.

In order to clarify C^2 and C^3 further, one can examine the individual concepts that comprise them in turn.

Command

What is entailed in command? Firstly it necessarily involves a 'mission' — the objectives which the commander and the personnel subject to him have been appointed to achieve. Next it implies 'authority', which allows the commander the right to give orders to others, ie his subordinates, and have them carried out.[6]

Thirdly command involves certain types of activity — planning, which is of major significance, since 'to command is to foresee'[7]; directing, ie the supervising of the execution of one's orders; co-ordinating, both within the commander's own section and with other sections, and lastly, controlling — that is checking the actual results achieved against the planned results.

These command activities are not carried out in a vacuum, but are directed towards certain resources — the most important of these are human resources, ie personnel. Then there is the broad category of material resources, including technical equipment and base facilities.

Control

As was shown under the previous heading, control is one of the activities that form part of the process of commanding. In this context it should not be confused with directing, which involves direct supervision of an activity as it takes place.

In the words of a pioneering management theorist, Henri Fay l, *Control consists in verifying whether everything occurs in conformity with the plan adopted, the instructions issued and principles established. It has the object to point* *out weaknesses and errors in order to rectify them and prevent recurrence.*[8] In other words, the term 'control' can be used to describe any process that has the effect of telling the commander where he is as compared to where he had planned to be.

Communications

The term 'communications' refers to any means of exchanging information of any kind between one person and another, other than direct verbal communication; or more abstractly, to any method of 'exchanging meanings between individuals through a common system of symbols', with the same proviso.[9] These symbols may take the form of spoken or written words, sounds or images. Communication as such may only be said to have taken place when information has been transferred *and understood* by the receiver.

Communications are thus one of the material resources at the disposal of a commanding officer. The importance assigned to this concept is indicated in its being included alongside command and control in the term C^3. The reason for this is that none of the activities involved in command — planning, directing, co-ordinating or controlling — can be carried out without the use of information conveyed by one form or other of communications.

Characteristics required in a C^3 system

Over time it has come to be recognised that there are certain characteristics that should be present in C^3 systems for them to function effectively.

Firstly, a C^3 system should be sufficiently comprehensive to enable the commanding officer and his subordinates to fulfil their mission. This requirement has a number of aspects — the commander himself should be assigned a degree of authority commensurate with the importance of the mission; further, he should be assigned with adequate resources, both human and material, to make it possible to achieve the aims of the mission. In particular, the information provided by the communication network of a C^3 system should be in enough depth to allow the commander and his staff to plan and control the fulfilment of their mission effectively.

Secondly, there should be sufficient potential for flexibility in the system to allow it to adapt to changing circumstances. The importance of this requirement can be underlined by demonstrating the degree of change that military operations may be subject to. Such operations often spread over large areas in space and time, involving many factors, many of which may be subject to change.

Furthermore, the processes entailed in these operations are 'stochastic' ie the steps that make

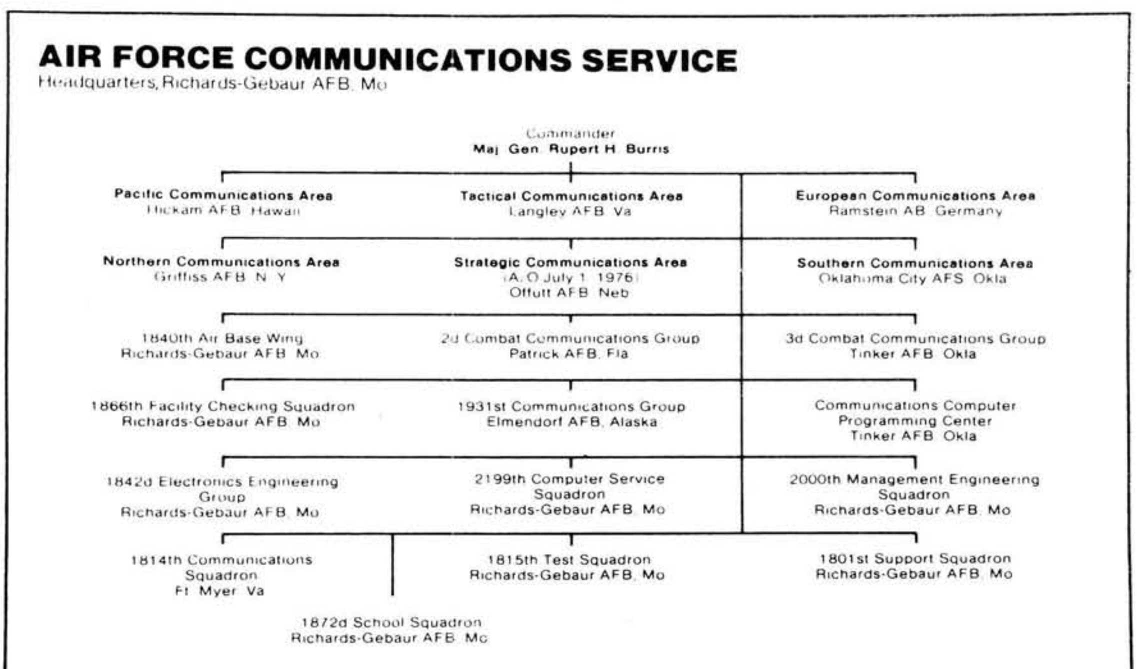

Diagram of Communications network in the US Air Force

up these processes are predictable only as possibilities, not as certainties. Moreover, since these processes are two (or more) sided, assumptions concerning the nature of an enemy's forces and plans may be shown to be incorrect during the course of operations, thus necessitating adjustments in a C^3 system. In addition the military process may be subject to policy changes by higher authority during the course of military activities — these decisions on policy may be made by political authorities and may be unrelated to the progress of operations. With all this potential for instability, it is clear that any C^3 system should have considerable flexibility.

The third general requirement of a C^3 system is that it should be characterised by unity of command. There should be a single point of ultimate authority from which all subordinate authority derives. The individual in this supreme position is ultimately responsible for deciding how the assigned mission should be carried out. Adherence to the principle of unity of command has the effect of reducing uncertainty and ambiguity in the planning and execution of the mission's objectives.

At the same time a C^3 system should allow for effective delegation of authority, as a commanding officer can obviously not direct and control all the activities of the section under him personally. Once again, an important element in effective delegation is a sound system of communications between a superior officer and his subordinates, so that the former may have sufficient information to make a wise decision as to when to delegate. Clearly this is not usually a serious problem when a superior and his subordinates are in physical proximity, but it may become one when they are separated and obliged to rely on communications equipment to exchange information.

In addition, the principle of restricted span of control should be observed in a C^3 system. This recognises that there is a limit to the number of subordinates a person can direct efficiently. This principle derives from the psychological theory of 'span of attention', which holds that the number of separate items the human brain can attend to at any one time is strictly limited. Traditionally the extent of maximum effective span of control has been placed at between three and seven subordinates reporting to a common superior officer.[10]

Further demands made of C^3 systems result from the fact that they do not operate in isolation, but must be interoperable with other sections of the organisational environment in which they are situated. In general, any C^3 system has to be compatible but with the superior authority from which it receives orders concerning its mission, and with other C^3 systems of an equivalent status as itself. In the case of a strategic C^3 system belonging to one of the members of *NATO*, for instance, the superior authority would be the government of the country concerned, while the equivalent C^3 systems with which co-ordination would be necessary would be those of the other *NATO* member-countries. Incompatibility between a C^3 system and other systems may result not only from differences in technical equipment but also from differences in standard procedures and modes of expression which may lead to misunderstanding or even mutual incomprehension.

When one considers the technical requirements of C^3 systems in general, one can state that the different types of technical equipment in such a system should have parallel capabilities and capacities to ensure smooth functioning and moreover that these capacities should be reconciled with the numbers of personnel available and their training level.

To illustrate this point, one writer uses the imaginary example of a 'Super Sensor'.[11] This sensor system is capable of rapid data gathering and coupled with a massive computer system it can also display varied information. But in the imaginary situation put forward, when it is introduced into a distant local command centre, due to maladministration the only link between it and the central command centre is a 100 word a minute printer channel, resulting in serious delays. Consequently one second's worth of information from the 'Super Sensor' takes one and a half days to reach the central command centre. To make matters worse, when adequate communications equipment is installed, the existing personnel are lacking in numbers and training to operate it effectively.

Certain other requirements are made of a C^3 system insofar as it is a means of collecting, conveying and processing information. These are that the system should be capable of presenting information in an intelligible form to the individuals responsible for making decisions. Furthermore this information should be relevant to the decision-maker's mission, and should be supplied in the right amount of detail — sufficient to make an intelligent decision possible, but not too voluminous to require too much time for its analysis.

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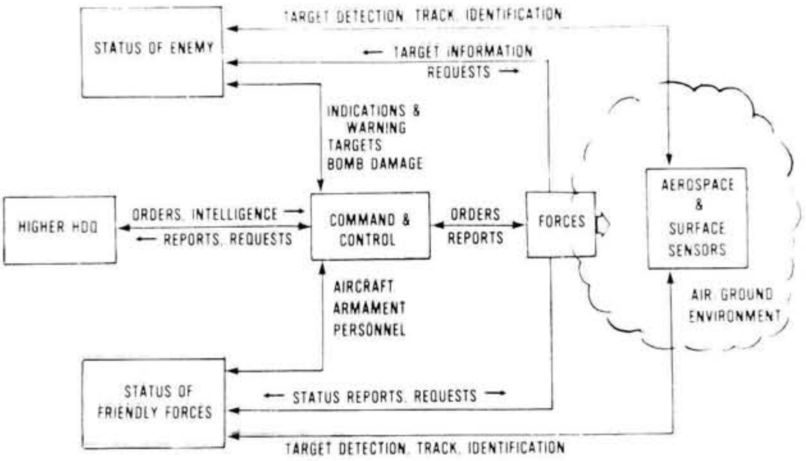

Figure 1. Information flow in C^3

Information Flow in C^3

This demands considerable flexibility in the information process, since the nature of information required varies considerably according to circumstances. As Lt Genl Marsh of the US Air Force puts it, *the first time an enemy soldier steps across the boundary line, everybody — including the President — may need to know. After that an individual soldier crossing the boundary line may be of interest to no one.*[12] To complicate matters further, the information system should be able to provide the right information at the time when it is needed. This necessitates the capability of storing information, since those in command may not wish to act upon information immediately it becomes available, but may require it some time later.

Certain requirements which apply specifically to communications systems may be dealt with here.[13] Firstly such a system should be 'survivable', ie it should not be vulnerable to physical destruction. (This requirement applies of course to all the other types of C^3 installation as well.) It should not be open to exploitation (the reading of text and the location of emitters) or 'spoofing' (the introduction of false messages). Finally it should be resistant to electronic jamming.

Lastly, another requirement may be mentioned that applies to both communications systems in particular and C^3 systems in general. This is that of simplicity. Other things being equal, a communications or C^3 system should be as simple as possible. The degree of complexity of a system has implications for its cost and for its effectiveness should part of it break down. Generally, if two systems under consideration fulfil all other requirements equally well the simpler one should be chosen in preference.

Naturally the requirements of C^3 systems vary depending on whether they are being used for tactical or strategic purposes. *The basic requirement for tactical C^3 is to let the commander see the battlefield situation, know where the enemy is, where his own forces are, and how they are moving in relation to each other.*[14] Detailed coverage of this kind of the total area under a strategic command would be undesirable in a strategic C^3 system since those in control would be swamped with excess information. Rather such a system should provide a clear overall picture of the general situation, while at the same time having a capability similar to that of a zoom lens — when necessary it should be able to provide a detailed picture of individual areas where the state of affairs is critical.

C^3 and Technology

Various types of technology form part of C^3 systems. Firstly there are information-gathering devices and systems, sometimes referred to as 'sensors'. Into this category fall items such as infra-red cameras and radar, with each type of sensor presenting information about different aspects of the situation under scrutiny. In the second place, there is communications technology, which is concerned with the conveying of information — radios, telex systems, satellites, etc. Thirdly there is technology related to the processing of information into forms intelligible to and convenient for the user. Data-processing computers play a significant role in this category. Sometimes the various technologies in weapon systems are also classified under the heading of C^3 — those relating to target acquisition for example.

Much has been written about the relationship between the development of technology and the development of C^3 systems. Briefly, it can be stated that the evolution of technology affects C^3 systems in two ways. Firstly technical advances in military weaponry create new demands for C^3 systems to react much more quickly to threats of airborne attacks from other countries.

Secondly technological advances make it possible for C^3 systems to respond positively to these increased demands that are made of them. For instance, the increase in the mobility of ground forces has made it desirable for the military equipment necessary for C^3 to be less bulky and more easily transportable. This need has been met, since advances in microcircuitry have now made it feasable to store an air defence control system which in 1957 was housed in a four-storey cement building in one small rack of equipment.[15] Furthermore, whereas previously such an installation required as much electrical power as a fair-sized town, now its requirements are comparatively low. This is merely one of the many possible illustrations of the evolving technology of C^3 systems rising to meet the demands made by the changing nature of military operations.

It is therefore evident that there is a dynamic interplay between evolving technology on the one hand and the make-up of C^3 systems on the other. In the short term, technology may be said to play the dominant role in the relationship, since elements of current C^3 systems are planned in terms of existing technology. In the long term, however, the demands of C^3 systems are dominant, since researchers are able to modify current technology to meet the requirements of C^3 systems that are still in the process of development.

Related Issues

At this point it is possible to discuss two matters that are often mentioned in relation to C^2 and C^3 — staff and line functions, and management in relation to command.

i. Staff and line functions

To clarify the difference between these two types of function, one should focus on the questions of authority and responsibility. While those fulfilling a line function have the authority to supervise the execution of their missions, and the responsibility to ensure that this is in fact done, those in a staff role do not share such authority and responsibility. The latter act in a specialist advisory role, assisting those in line positions to carry out their missions.

The staff relation was developed to assist those in line positions without interfering with unity of command. As military forces expanded in size and complexity, those in command found that limited time and lack of specialised knowledge prevented them from giving adequate attention to all aspects of their work. As a result staff functions were developed. The staff thus perform an auxiliary role, providing advice and information, while authority over military operations remains with the line.

Staff elements may exist at a number of levels within an armed force. As might be expected, they increase in size as higher levels of authority are reached, since the extent of their sphere of activity widens. At the highest level, where the staff elements' activities relate to the whole armed force, they are generally referred to by the term, Chief of Staff, followed by their specialised area. The 'general staff' of the 19th century German army, which acted as a model for many modern armies, contained four specialised staff elements — personnel, intelligence, operations and supply (logistics).[16] Other elements have been added in many armies, such as finance and communications.

Three types of everyday staff activity may be distinguished.[17] Firstly there is the 'core' activity of the staff.— the formulation of policy, plans and objectives for an armed force. Then there is the monitoring role, where staff elements act as 'watchdogs' over operational and support units, to ensure that they are carrying out their assigned roles effectively. Thirdly there are staff activities relating to internal management and support. This type of 'housekeeping' activity has become necessary because of the rapid increase in the numbers of those in staff roles. In exceptional cases, certain staff elements may be utilised in operations, but only when the use of field personnel would be illogical or impractical.

ii. Command and Management

Considerable controversy has been generated over the question of to what extent military commanders should regard themselves as managers. It is not necessary for the purposes of this study to give a detailed listing of the characteristics desirable in a military manager, but to clarify the controversy, it may be helpful to summarise one recent writer's views on the issue.[18]

Carrington sees the principal differences between management and command as lying in their respective attitudes to uncertainty. While military command tends to attempt to eliminate uncertainty and to strive towards certainty and uniformity, management takes risk and uncertainty into account and attempts to turn them to its own advantage.

In his view, other differences in viewpoint stem from this basic difference. While the command outlook is that the source of authority is from above, *the management standpoint is that authority derives from below through acceptance by one's subordinates. Thus while from the command viewpoint an order holds authority once it is given by a superior officer, from the management viewpoint such an order is authoritative only when it has been understood and accepted. Further, while command denies that responsibility for a task can be delegated, management supports this idea.*

While one might criticise Carrington's views on the grounds that he exaggerates the differences between the attitudes of command and management, he himself concedes that the two concepts would be regarded as complementary, and not opposed. Like many other writers, he believes that the military commander can improve his effectiveness by assessing the techniques and attitudes of management and adopting those aspects that are suitable for his particular position. To use Carrington's own words, the commander can benefit himself *by recognising that (in his own command) there are many elements of a management situation, by understanding what these elements are, and by knowing how to make the most of each and all of them to help ensure his success in the art of command.*[19]

Conclusion

So far focus has been on the concepts underlying C^2 and C^3 and giving some idea of what is entailed in these two concepts. To bring the various strands of this overview together, it may be helpful to quote the definition of a C^3 system given in the dictionary of military terms approved by the *US* Joint Chiefs of Staff. According to this source, a C^3 system is defined as follows: *'The facilities, equipment, communications, procedures and personnel essential to a commander for planning, directing and controlling operations of assigned forces pursuant to the mission assigned.'*[20]

Recent Trends

Before considering the various trends that are evident in C^3 at present, it is desirable that one should have some idea of the context in which these trends are taking place, and the demands that are in consequence being made of C^3 systems. Very briefly, the most significant demands being made of C^3 systems arise in the first place from the ever-increasing sophistication of weapons systems. These have increasingly greater destructive power, speed and range, so that the extent of the conflict area is continually expanding further beyond the range of 'line-of-sight' and 'over-the-horizon'. Consequently there is a corresponding reduction in the amount of time available to receive and analyse information, make decisions and promulgate them. At the same time there is less margin for error, for the consequences of a decision based on faulty judgement could be catastrophic.

Secondly, it is increasingly common for conflict to take the form of 'total war', which is conducted simultaneously in all spheres — political, economic, diplomatic and military. Consequently the amount of information that is required of a C^3 system is correspondingly greater and its content wider-ranging than previously.

Management of C^3

Firstly, one can trace the evolution of general attitudes and uses of C^3 since World War II in those countries most advanced in this field in the West — the *USA* and other members of *NATO*. Other countries are evidently passing through the same progression of stages in their attitudes to C^3, but at later dates.

The first stage of C^3 was characterised by a 'black box' approach to development — the USA passed through this phase in the late 1940's and the early 1950's.[21] During this period C^2 equipment was produced for specific and limited applications with little regard for the environment in which it was to operate. At this point technology was at a level where considerations of size, weight, costs and reliability made it seem undesirable to construct anything more ambitious than a 'black box'.

The 'black box' approach was followed by the era of the 'systems approach' — in the late 1950's in the USA. This second stage was reached when it was realised that much time and effort was being spent on attempting to co-ordinate the outputs of various 'black boxes' operating within a system, often with limited success. As a result those in control appreciated that it would be wiser to design the system as a totality from the start, thus minimising problems of interoperability within a single area such as intelligence or logistics.

In the present decade, with the steady expansion of C^3 the 'systems approach' has in turn been superseded by a new approach concerned with the overall architecture of C^3 systems. With the multiplication of C^3 systems, the question of interfacing and interoperability again became a problem at this more comprehensive level, and now the major concern is with the effective interlocking of sub-systems within the overall structure.

Automation

Like many non-military areas, C^3 has been characterised in recent years by a rapid increase in automation. This section will be concerned with examining how the various roles that machines can fulfil within C^3 have evolved and expanded in recent decades.

i. Record-keeping

There seems to be general agreement that machines should be used as far as possible for the simple function of counting, sorting and record-keeping. Having personnel to perform these elementary tasks manually is slow, wasteful and inefficient; machines carry them out more efficiently, as they are not subject to lapses in concentration and other human weaknesses. As one author points out, anyone who doubts this should consider whether he would favour returning to a manual system of airline reservations.[22]

Recent years have seen a considerable growth in the use of computers to perform these elementary functions — for instance, in keeping records of stocks in military stores. Perhaps the most developed form of computer performing this function is operated by the Defence Logistics Agency in the United States.[23] On receiving a requisition for an item, the computer checks the nationwide inventory of the item requested, and transmits an order to the depot nearest to the point from where the requisition originated.

Despite the large amount of ground that has already been covered, there is plenty of scope for increased use of machines for the functions of counting and sorting. One writer predicts that the tactical C^3 system of the future *will undoubtedly look to machines to log, compile and correlate sensor information, subtract bombs when they're dropped and fuel when it's used, maintain the target list and keep track of sorties available.*[24]

ii. Gathering of information

The second role that machines are capable of performing in the context of C^3 is that of the gathering of information. Again there has been a marked expansion in these activities over recent years, both as a result of the improvement of the capabilities of types of equipment already in existence and of the introduction of new kinds of equipment.

Through the development of the various types of 'sensors' - radar, conventional cameras, infrared, to name the most important — a greater coverage of the various aspects of a situation can be obtained, thus making a more comprehensive picture possible. Furthermore, new developments in sensor technology have widened the range of conditions under which evidence can be collected. The use of infrared and image intensifiers have made it possible to survey a battlefield situation at night or at any time when visibility is poor.[25] At the same time sensors have become less cumbersome and easier to use.

The 'information explosion' in C^3 has inevitably had consequences for other parts of C^3 systems — it has become vital that there should be elements in C^3 capable of processing large quantities of information, 'sorting the wheat from the chaff' and summarising the relevant material.

iii. Conveying of information

Another possible use for mechanical devices is in conveying information, and various developments have occurred in this field in recent years. Probably the most notable of these is the introduction of communications satellites, which have greatly increased the range and capacity of communications. The latter characteristic is significant because it means that more information can be communicated simultaneously.[26]

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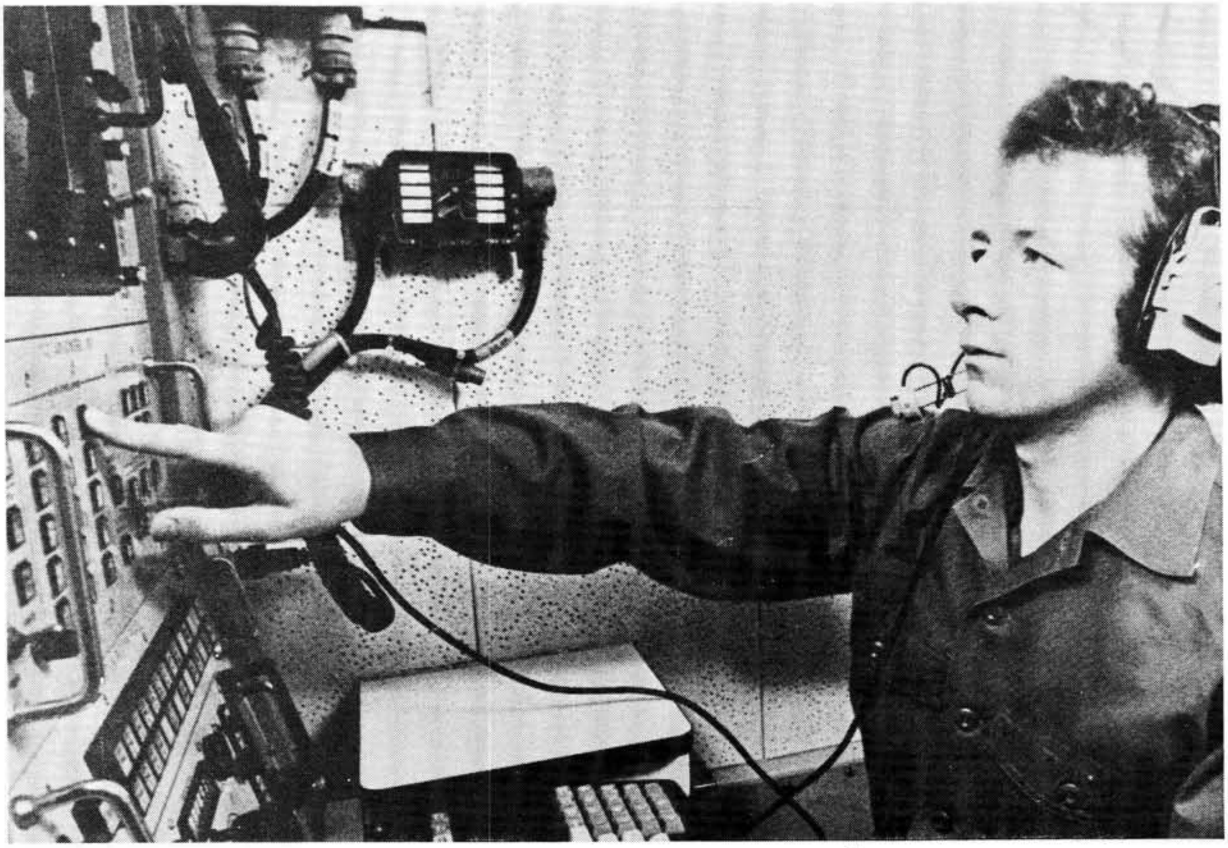


The Traffic Jammer poses a severe threat to efficient C^3 systems

At the same time jamming techniques have grown more sophisticated, but advancing technology has supplied the means to counter this threat. Some of the increased capacity now available can be traded off for robustness against jamming, so that it is still possible to transmit a smaller volume of data through a 'jamming environment'.

Recent years have seen much attention being paid to the development of message-switching centres, whose function is the sorting and transmission of both voice and data messages. A notable advance in this field is the replacement of conventional radio call-signs with dialling systems, which have in turn been superseded by the use of push-button devices making direct contact with the desired party possible almost immediately.[27] Such devices have been introduced in areas where operational urgency rules out time-consuming processes such as dialling and issuing radio call-signs.

Another significant advance that has taken place in message-switching centres is the use of 'packet-switching' for the transmission of data. This technique allows for the breaking down of each message into blocks, which are transmitted independently though 'tagged' with the same destination.[28] Individual packets of the same message can sometimes take different routes, only being reassembled to form the whole message when the final destination has been reached. This technique has the advantages of swiftness, since any message will be routed through the least busy lines; and of giving almost immediate precedence to high-priority messages, since high-priority packets can break into a string of low-priority packets.

The increased capacity of message-switching centres for rapid transmission of messages is at present placing considerable pressure on communications centres which are responsible for preparing messages and distributing them to the right people. Up to now these operations have generally been handled manually, which has sometimes caused serious delays.[29] While a limited degree of automation has taken place within military communications centres in certain countries, there is evidently still considerable scope for further automation in these installations.

Thus in the field of communications generally, there has been considerable progress recently towards the goals of making the transmission of information swifter and more reliable. In addition, as has happened in the field of information collection, technological advances have made communications equipment less bulky and easier to transport.

iv. Processing of information

As far as the automation of the processing of information is concerned, a rapid expansion of this function has been necessitated largely as a result of the need to store large quantities of information emanating from the 'information explosion'. Storage of information is clearly necessary, since those in control of a C^3 system may not need to make use of information at the time when it becomes available, but may require it many months or even years afterward. Certain technological advances in computers, spurred by the demands made of information systems in commerce as well as the military, have made it possible for this storage requirement to be met.

Much progress has yet to be made in the sphere of isolating relevant and convenient information for those in key positions in C^3 systems. The problem of sorting relevant data from the mass of incoming information is a pressing one, particularly at a strategic level. Obviously here the total volume of information coming in from all the various sectors of operations will threaten to swamp those in command, unless the task of sorting 'the wheat from the chaff' is done effectively. Certain techniques of classifying information according to its usefullness have been introduced to deal with this problem, but they are on the whole evidently not highly developed as yet.

The introduction of various types of display console has contributed much to the convenient presentation of information once it has been processed. Such consoles may utilise cathode ray tubes or 'plasma panels' (using gas discharge techniques), and may display video images, graphics and/or alphanumeric information. A further factor adding to the utility of these consoles is that they may be programmed on a keyboard to respond within seconds to the operator's enquiries.

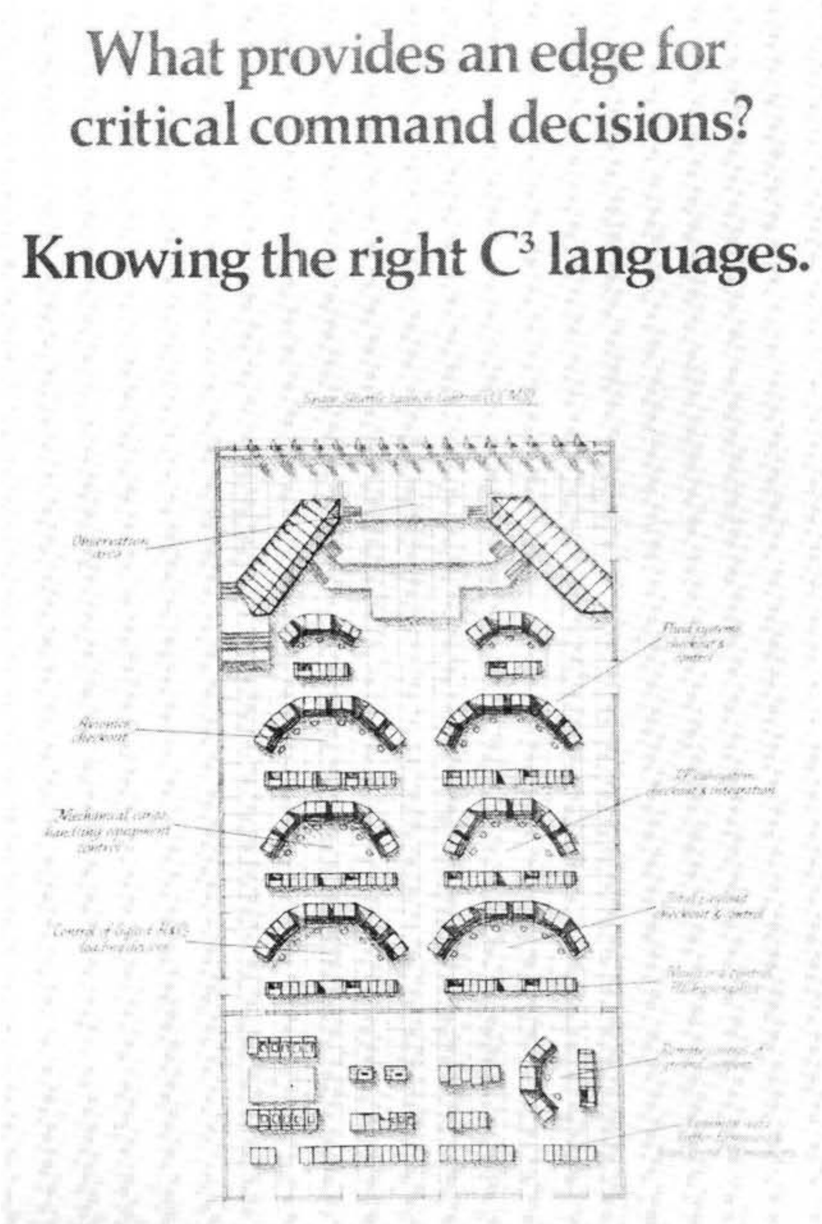
v. Decision-making

Thus far this section has been concerned with discussing various forms of automation as aids to decision-making for key personnel in a C^3 system. In recent years the possibility of programming computers to reach decisions concerning tactics and strategy themselves has been mooted on occasion.

This role has been most fully developed in the USA in sub-sections of the strategic offence and defence system relating to missiles, and in tactical air defence systems.[30] Here the inputs of information from the various types of sensors employed can be qualified and digitised for computer evaluation and decision-making. Here furthermore the time interval between reception of information and the necessity to act upon it is too short to permit human evaluation and decision-making. Clearly however these computerised decision-making systems are situated within an all-embracing C^3 structure where final decisions are made by the supreme commander in consultation with his advisors.

But in many areas of C^3 — notably tactical C^3 for land battles — there has been little progress towards allotting computers roles in decision-making. There are a number of reasons for this. Firstly in battle-type situations there are an immense number of variables. One researcher in this field states that 'the large number of variables — men, weapons, enemy, terrain and weather — involved in the actions of a battalion-size unit would require 10^{500} computations to determine the best tactic by examining the effect of all possible combinations of factors. This number is one trillion multiplied by itself over 41 times.'[31]

In addition it is impossible to cast a battlefield commander's problem in the form of a single set of binary choices.[32] For even if a computer could formulate tactics on information supplied at one stage of a battle situation, within a short time of its plan being put into practice, the commander would be required to respond to unpredictable developments. Each of these developments represents a choice-point for the commander, and the possible paths ramify so rapidly that computerised pre-planning is impossible. Furthermore in a battle situation there is the additional danger that the computer's requirements may force the programmer into arbitrary resolutions of the ambiguities inherent in the situation or in certain military principles applicable to the situation.



Development of C^3 systems is important in the military world

Despite progress in the fields of strategic offence and defence, these difficulties in the realm of tactics lead one writer to conclude that *'at present, the best C^3 technology can do for the tactical commander is provide him with the latest, best data in the clearest possible form and at his greatest convenience.'*[33] Like other writers, he nevertheless does not discard the possibility of progress in computerising decision-making in tactical C^3 in the future.

Key technologies in C^3

Now that the evolution of automation in C^3 in recent years has been examined, it is possible to go on to isolate three technologies which are the key significance for current and future developments in C^3.

It is generally agreed that microelectronics is the most important technology influencing the development of C^3 systems at present, and that with its potential for rapid growth, it will probably be so for some time to come.

The rapid evolution of microelectronics began with the replacement of the vacuum-tube by transistors from the 1950's onwards. In the early 1960s integrated circuits were introduced, consisting of at least ten transistors on a chip of material ½ cm square. These were followed in turn by circuits featuring medium-scale integration *(MSI)*, and now the era of large-scale integration *(LSI)* is here, with a thousand transistors on a chip of the same size. What is more, there is still potential for development to the stage of very large-scale integration *(VLSI)*, with ten thousand transistors on such a chip. To illustrate the significance of these developments, one can use the example of *ENIAL*, which was the first electronic computer ever built.[34] It used vacuum tubes and occupied several large rooms — nowadays a computer of the same capacity could be built to fit into one's coat pocket.

The significance of these developments for C^3 is considerable. In general they mean that many types of C^3 equipment have become less bulky, more easily transportable, cheaper, more reliable and lower in power requirements. The effect for computers in particular is that they have become much more widely useable, and the way has become open for a considerable variety of applications outside fixed installations. For instance it has now become feasible for a battlefield commander to keep a computer terminal with him to aid him in decision-making in the field.[35]

A second area of significant technological development is in software (ie programming) technologies relating to computers. The interlinking of a number of different computers has become possible — this process is known technically as 'netting'. The main benefit of this technique is that it makes it possible for a large task to be distributed among a number of computers, and to be completed more swiftly in this way. These developments also make possible the interlinking of tactical electronics units of the same military force in different areas. Such a system is in the process of development in the United States under the name of 'Joint Tactical Information Distribution System'.[36] This system will enable mobile units to exchange information (mainly in digital form) with each other through a process that is both automated and secure.

Thirdly, an area of technology which is likely to be of considerable importance for the future of C^3 is fibre optics.[37] It has now become possible to send light signals through thin glass or quartz fibres over long distances, and utilise these signals for the purpose of communicating. These fibres can also be combined into small but strong cables, and used to send signals on land and under water. These innovations potentially hold considerable benefits for C^3, since these fibre cables can be substituted for conventional cables in many cases, with the advantages of reduced weight, volume and also cost — in the long run, at least. Electromagnetic interference — both accidental and intentional — can also be reduced with this new technique. Since it is predicted that the technology of fibre optics should become generally available in the near future, its impact on C^3 systems should be felt soon.

Centralisation versus decentralisation

The overall trend in the C^3 systems of the leading powers since the start of World War II has been towards centralisation. The major factors leading to this long-term trend are as follows — the threat of catastrophic nuclear attacks, which necessitate a swift response from a central command capable of co-ordinating all a country's military resources; the development of computers capable of central handling of numerous routine functions previously dealt with by personnel at lower levels of military command, and lastly, the evolution of sophisticated communications capable of keeping central commands in secure contact with tactical forces.

Yet in the last few years the process of centralisation has slowed considerably. Evidently a point of equilibrium is being reached between the forces towards centralisation and those leading to decentralisation — at least in the C^3 systems of the most advanced countries. It therefore seems a suitable point to examine the nature of these conflicting forces.

As far as those leading to centralisation are concerned, in addition to those mentioned above, one can cite the desire of those in overall command to have as much control as possible over the activities of the sections under them. Further, many problems relating to military operations cannot be subdivided, since they involve several different fields of military activity — logistics, communications and others, apart from combat itself — such problems have to be dealt with by central command. Finally, from a technical point of view, the unified handling of data and communications by computer and other equipment at a single central point eliminates the problems of interfacing and interoperability between differing types of equipment at lower levels.

When one comes to consider the arguments against excessive centralisation and in favour of decentralisation, one can mention first the possibility that those in a highly centralised command may become swamped with excessively detailed information and be required to make too many decisions concerning comparatively minor details. Further, in the tactical sphere, local commanders may be able to make better decisions concerning their areas of operations, since they are likely to have a better grasp of the actual situation. If they have the right to make major decisions removed from them by central command, they may lose the necessary flexibility and be unable to respond sufficiently quickly to new developments at the tactical level.

Moreover, excessive centralisation exposes an entire C^3 system to total breakdown if the central installations are physically destroyed by an enemy. Protective 'hardening' of these installations may reduce this risk, but can never remove it completely if an enemy is sufficiently determined. A final objection to highly centralised C^3 is that it makes the entire system excessively dependent on reliable communications. One writer states rather pessimistically that *in many more instances than anyone would like to admit, the communications to support the centralised C^2 concept are just not going to be available, especially in a conventional war such as might be fought by NATO.*[38]

Conclusion

Many aspects of C^3 have changed considerably in recent years, and there is great potential for further change in the future. As was noted earlier, there is a dynamic interaction between technology on the one hand and the nature of C^3 systems on the other. In the short term technology tends to be the dominant partner, since current C^3 systems must be designed in terms of existing technology. In the long term the requirements of C^3 play a more dominant role, since technology can be moulded to meet the requirements of the C^3 systems of the future.

Changes in C^3 are one category of the multiplicity of changes that are constantly occurring in the military environment. Writers on military topics frequently emphasise how important it is that those in key positions should come to terms with change — both the changes forced upon them by external pressures, and the creative internal adjustment of their own sections. Those who learn to deal with change effectively will be masters of change[39] whereas those who fail to acquire this skill will become its slaves.

Cartoon depicting the strain of modern and complex C^3 systems on the human mind

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Foot-Notes

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