C2 - Command and Control: A System of Systems to Control Complexity

Bernard Claverie
Bordeaux Polytechnical Institute

Gilles Desclaux

"Command and Control," or "C2," is the theoretical part of a set of means and methods (C4ISR) for managing large human complex systems usually engaged in operations and whose lack of effective management can have highly undesirable or even disastrous consequences. It is mainly used in military context. This article investigates the theory that supports C2 principles and C4ISR practice as well as their role in the regulation of complexity of regulating movement while being itself a generator of its complexity. The present analysis belongs to cybernetics and explores military applications and the status of C2 as a system of systems to control complexity.

Keywords: C2, C4ISR, command and control, complexity, cybernetics, management of complexity, military, strategy, system of systems

INTRODUCTION

Modern management of military operations is based on Command and Control (C2) design and is fully imbued with the new dimensions of information and communication technologies, and with Artificial Intelligence. In the 1980s, this invasion of technicality led to an evolution of the designation of the system as C3I, adding to the acronym the dimensions of communication and intelligence. At the turn of the century, technology was explicitly invited by evolving C2 into C4ISR, or even today into C4ISR-TAR, for "Command, Control, Communications, Computers, Intelligence, Surveillance, Reconnaissance, and Specific Target Acquisition and Recognition" (C4ISR Network, 2015). C4ISR-TAR is the acronym used in particular by the US Department of Defense (DoD) to designate all organized and structured military means and processes for the conduct of operations, and their command and control. This technological movement has brought C2 into a definition centered on the use of techniques and methods.

At the same time, and as some authors point out (Alberts & Hayes, 2006), the field has been constituted in a regulatory manner based on institutional and legal definitions, and with a managerial dimension of legal value. This is the case with DoD or NATO texts. For the "DoD Dictionary of Military and Associated Terms," the C2 corresponds to "the exercise of authority and direction of means assumed by the commander of military forces attached to him for the achievement of his mission" (JCOS-DoD, 2008). "The exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of his mission, also called C2." (Online Department of Defense Dictionary of Military and Associated Terms).

The term "Commander" corresponds to a functional hierarchical position as recognized by all actors at a given time. His role may exist for a very short time, from a few hours to a few days when he is an "On-Scene Commander" (OSC), or it may correspond to a longer duration ranging from several months to a few years. It is rarely definitive for a specific person —except in special cases encountered in certain monarchical, religious, oligarchic regimes— but requires a specialist who has undergone lengthy and specific interdisciplinary training. The DoD definition specifies that C2 is assumed "thanks to an organized set of personnel, equipment, communications, devices and procedures that are used by the commander for the planning, direction, coordination and control of forces and operations in the performance of his mission." This notion of "Commander" is strongly associated with that of Strategy. Strategy is fundamentally what transforms an unsatisfactory actual state (as a crisis awareness state) to an expected final state (see Figure 1). C2 is the method used to lead this strategy until the success of the action.

FIGURE 1

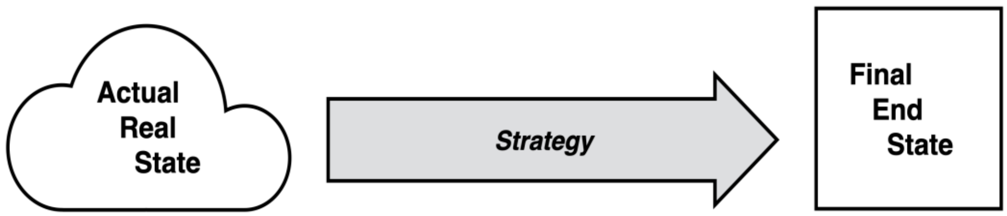


Figure 1: Strategy is the military art of making an actual state evolve toward a desired strategic final end state. It is concretely, for the commander, the best way to move from an initial real state to an expected end state.

Strategy is neither an intention nor a plan; it is, rather, an act of determination (Commander's Intent). It is primarily worn by an individual and the C2 is the action of a staff. It is a force multiplier that allows bringing out the right strategy and applying it with performance: better understanding, better decisions regarding the application of force, overcoming difficulties and circumventing obstacles, and minimizing risks while better grasping opportunities. When a commander declares that he has strategic superiority, he says that he can decide the where and when of confrontation and even the opponent. The C2 device then allows the exercise two forms of power: the ability to act in the moment and the capacity to project that potential going forward. It is due to the performance of this device that it can decide faster than the opponent or competitor while maintaining the initiative.

The "NATO glossary" takes up this definition: C2 is "the set of functions of commanders, their teams and other command corps for maintaining forces, preparing operations, and directing troops for their missions." The concept encompasses various dimensions specified in the glossary beginning with information and "its continuous acquisition, merger, examination and representation, as well as its analysis allowing assessment and situational awareness." Added to this is "the planning and constitution of the command project (plan), the distribution of resources and tasks to the different elements of the forces (tasking), the operationalization, organization and maintenance of the cooperation of these forces and all forms of their support." These definitions illustrate a series of actions that give C2 a dimension of information, analysis, decision-making, logistics, and implementation of means, and support to respond to a situation to be maintained or to evolve in a favorable way (Desclaux, 2006).

For Alberts and Hayes (2006, op. cit.) concluded that C2 must overcome these regulatory or technical definitions to address an explicitly scientific dimension. Thus, theorization covering the whole of C2 has developed, of course at the initiative of US DoD and NATO staff, and also major industrial suppliers of the technological concerned domain. Their studies define a generic dimension of C2 and constitute a specific theoretical field of study of "command and control."

Why is this theoretical field different from the purely technological aspect of these devices or regulatory aspects of management and management methods? In fact, the modern systems concerned are extremely complicated and their use complex. They involve many interacting technological and human elements: human–human, human–technology, and technology–technology. These sources of complexity address all processes and interactions on several levels and between these levels. It is this anthropotechnical dimension that is the main source of complexity, uncertainty, and incompleteness of models of understanding, and often of difficulty in mastering C2.

This article briefly addresses the dimension of complexity and the multi-dimensionality of the theoretical spaces of implementation and the application spaces of "command and control."

Domains of Application of C2

While C2 is a primary dimension of modern military organization (Boyes & Andriole, 1987) of all the different forces and their interoperability (Joergensen et al., 2005; Larsen, 2006), including for coalitions, it also concerns other less martial areas of application. For instance, C2 is used in particular in various crisis management sectors. This is the case with organizations in charge of public safety, those managing the transport and dynamics of vehicles fleets, fluids or energy that can be malfunctioned, those in charge of environmental safety, and in the fight against pollution, havoc related to nuclear accidents, or the expansion of epidemics and epizootic diseases, etc. On the other hand, companies or organizations managing complex programs often require strict error control or trajectory deviation management for a specific objective. This is the case for space programs and all construction or implementation devices requiring strict anticipation and precision, with immediate control of deviations and anticipation of any risks. These dimensions — crisis management, error control, and anticipation of consequences— are characteristics of domains using C2.

In its broadest sense, C2 is, therefore, both a method and a process associated with a complex activity that requires totally or partially strict control. This is defined by an "Operational Design" (see Figure 9), which must lead to the expected final effect by the synchronization of essential actions. The decision can be shared to all levels in a structure that favor agility and delegation within the defined framework. Defense is then only a particular case of application. Nevertheless, the principle of C2 comes from military organizations and we note its influence in these various other areas of application. The pervasion of methods is obvious, just as a martial vocabulary passes metaphorically in the civil domain (Wee et al., 1991): commercial campaign, price war, staff, marketing warfare, war-room, conquest strategy, etc. and, more traditionally, general director, industry captain, etc. (Le Roy, 1997).

It is noted that C2 methods can be applied to a greater or lesser extent to institutional and commercial civil systems. The elements of system complexity are addressed according to the same principles. C2 then makes it possible to consider and structure approaches organized toward a goal defined by the command, controlled by a human device, informed by the various statistical contributions, dashboards, and strategic indicators, and increased by a technological set of information, communication, and decision support. In fact, C2 is the best method to lead a strategy and, thus, the best way to go from an actual state to a desired end state.

FIGURE 2

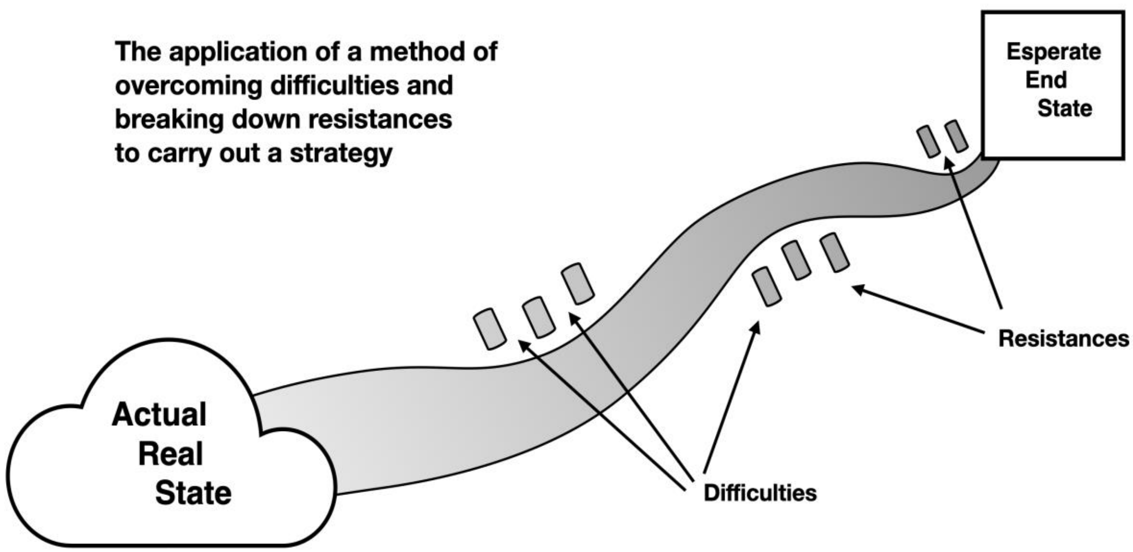


Figure 2: Strategy is forced to circumvent the obstacles in order to avoid difficulties and overcome resistances while progressing from an unsatisfactory initial state to an expected end state. C2 is the method to conduct the Strategy to achieve the desired goal in its complex environment.

Command and Control

In the social sciences domain, "Command" is the ability of an individual or staff to acquire or exercise authority over one or more other individuals or groups according to criteria recognized by them. At the forefront is competence, but also popularity or hierarchy as part of a leadership process. In institutional fields, particularly administrative and military, the command designates by metonymy the authority itself or often the seat of this authority. Control, on the other hand, represents the ability to direct a system and maintain it in a state that allows concrete and defined action. The concept is directly from the field of cybernetics. In particular, it aims to control or even eliminate change and organizes the system by fighting entropy. It refers to three complementary dimensions. The first is informative, giving measurement values of the state of the controlled system, or elements of the system to verify whether they inscribe their temporal evolution in a given space of variation. The second dimension is preventive, anticipating the possibilities of drift and preventing deviations from waiting or not corresponding to the desired objective. This second dimension can be considered as characterizing the negative part of control. The third is incentive of a positive nature by promoting the desired opportunities and promoting their implementation, development, and expression according to the objectives ordered. The purpose of Control is to reduce uncertainty in the system. It then becomes one of the main sources of stress of human organizations out of fear or anxiety of losing control or overcoming the capacity to return to the desired state. The "Psychology of Control" is an example of the role of such deficits in the appearance of anxiety and its management through control processes.

C2 must be approached from this cybernetic perspective. Cybernetics is a science that deals on the one hand with identification, analysis, and modelling, and on the other hand with the control or regulation of dynamic systems. Its theoretical foundations are partly mathematics, signal theory, and information and communication technologies, and partly social sciences and biology. It uses tools such as logic and theoretical computing, and, as a result, allows experimentation on the effects of their implementation on concrete cases. It concretely addresses the functioning of systems and proposes an abstract approach. This is organized around the theorization of the logical structure of coupled system–environment functions and their mathematical modelling according to the rules of logic. We are talking here about "logic of automatic systems."

Endowed with its own theory, C2 differs from information theory, which builds a quantitative and objective definition of the notion of information, and from communication theories that study quantitative or qualitative indices of relationships between agents (machines, beings, and environment). It can be said that the deterministic aspects of C4ISR are studied by information theory, particularly with regard to the central points of information transformation and its coding, transport and transfer, filtering and storage, and, further downstream, of the value and meaning of information at each level of its processing. Command is only possible if it is based on control. Communication is the means of transporting data from one place to another, from one level to another, from the environment to the entire system, and from the elements of the system outside. Intelligence is the product resulting from the collection, analysis, evaluation, and interpretation of relevant data to achieve the desired result. These data are collected by sensors that transform information by essentially technological means, converting it into knowledge by the cognitive skills of the commander and his analysts.

This application component is in the field of Information Technology. It allows to command and control a system in accordance with a plan or specifications of its temporal evolution. We then mention the concept of piloting, which gave its name to cybernetics (Claverie & Desclaux, 2014). Cybernetics is, therefore, an art applicable to the theorization of C2, and C2 is a form of reification of cybernetics. Some authors even propose "a fusion of the two approaches" (Builder et al., 1999). With regard to the conceptualization of C2 and centered in a more abstract way on the understanding, design, and formalization of systems of action and regulation, we speak of "formal systems" whose quality is the independence of real media. Whether it refers to the artificial or natural world, abstract or concrete, the formal system is a theoretical being that can receive a conceptual declination. It transforms an abstract input representation, which can be of purely mathematical essence, of a given signal or series of signals, into an output representation while iterating its transformations at each level by feedback loops coupled with the environment or between different units of a calculation carried out by one or more internal programs. It is, therefore, a "computational being" whose transformations and those of the environment are part of algorithm theory (Claverie & Desclaux, 2015).

C2: From Old to Modern Conflicts

In ancient and traditional battles, the commander is usually surrounded by his staff in a high battlefield observation situation and with an immediate system of dispatch riders, allowing each sub-commander on the ground to receive orders to act or modulate the action of his own troops. For greater precision, blues fight against reds (or any other colors necessary for their distinction) to the sounds of their trumpets and drums. Thus, the commander uses his own eyes and ears to collect data, mobilizes his cognitive skills to process data and evaluate the flows and reflux of troops in battle, evaluates the choices available to him to define the actions most appropriate to the objective, implements his decision with messages and, if necessary, repeats the process by successive iterations until the objective is achieved (Cooper 1994), which is most often an attraction of the enemy. In such a process, command is obvious and control boils down to an iterative sequence of regulatory orders for the commanders of the engaged forces.

Modern military operations are fundamentally different: command, force control, and conduct of operations are of a different kind, and the objective is more influence than force (Warden, 1995). Thus, modern conflicts have completely changed the equation of command and control in the conduct of military operations. The First World War highlighted the importance of a series of dimensions so far neglected or considered secondary. Technology has progressed so much that it tends to change all modes of confrontation, referring the conventional to the past and the future to uncertainty. Invisibility replaced camouflage, itself generalized as the modern form of the colors of war, and has also imposed itself as an offensive weapon with the appearance of gases and other terrible means that today's nations agree to prohibit both their use and even detention. Air surveillance aircraft arm themselves and then influence the conduct of ground operations while discussions are still heated today between supporters and critics of killer robots and drones. Finally, information, access, dissemination, and encryption have become major concerns with cryptographic methods that have so advanced mathematical research and the safety of economic operations.

The Second World War and then the conflicts of decolonization pushed the equation even further with the appearance of the cybernetics of Wiener, Rosenblueth, Bigelow, McCulloch & Pitts (Couffignal, 1963), and computer science with Turing, Von Neumann, and their successors, with Steinbuch (1957) or Dreyfus in Europe who was at the origin of the word informatics in French in 1963 (for a review see Claverie, 2005). Information has become central, whether it is considered in its collection, analysis, transfer, distribution, and understanding by men. It is at this last stage that more recently the engineering of human–system coupling was formed with specialists who were directly inspired by the two previous movements: cybernetics and computer science. As General Moshe Dayan (1966) wrote: "Where are the good old days of simple war when, when the time of combat approached, the commander got on his white horse, and at the sound of the trumpet he rushed towards the enemy… shouting '*Follow me!'*?" Military actions have become technological, employing sensors, information, intelligence, and effective decision-making in situations of uncertainty for an action, itself marked by submission to the unexpected and the adaptation of the action, to often act remotely by actions of human or automatic vectors that self-regulate themselves according to the logic of the networks.

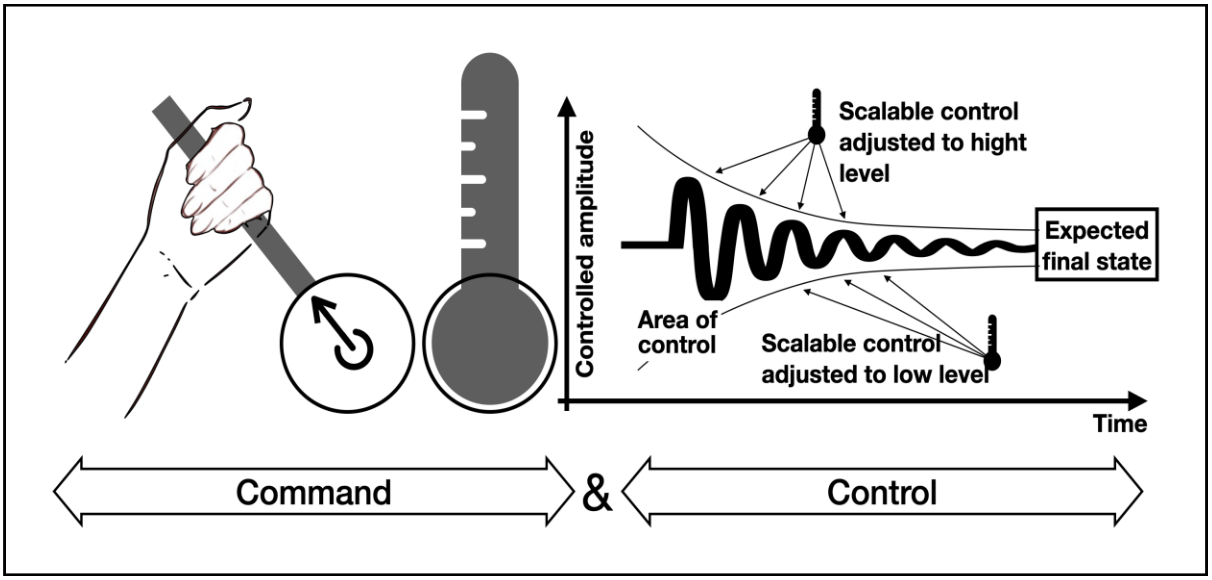
The return of brutal, high-intensity wars does not change this state of affairs. Information is everywhere, making its control all the more important. But technology and new methods of influence are now becoming major tools for manipulating information and altering the means of this communication, and aims at altering decision-making and inhibiting C2 by means of "cognitive warfare" (Claverie et al., 2022).

In such a context, command corresponds to the mobilization of available material and human resources such that it is possible to achieve a desired result. This result corresponds to a significant change in the state of the environment. Control consists of observing and measuring the current environmental situation in order to assess the difference between the system and the desired state, and issuing continuously adjusted guidelines that will maintain changes from the current state to the desired result or the maintenance of this state once achieved. In terms of conflict, surveillance, or peace-keeping, C2 focuses on a result that is not limited to the military field. Engagement is often even secondary, mobilized as a means of regulation or evolution, with logics of information, influence, "soft power," and surgical strikes. As Warden points out, "Contrary to Clausewitz, destruction of the enemy military is not the essence of war; the essence of war is convincing the enemy to accept your position, and fighting his military forces is at best a means to an end and at worst a total waste of time and energy" (Warden, 1995, op. cit.). Recent examples of high-intensity conflicts nevertheless put this logic at the forefront, bringing the fundamental importance of C2 to the forefront.

C2 as a Cybernetic System

Cybernetics is the science of systems regulation. Regulation requires (i) an objective to be obtained, for instance, a mechanical, thermodynamic, or biological state, and (ii) a device that aims to maintain the best possible balance around this state either by successive approximations or by maintaining in an increasingly precise control space around the value of the target state. The determination of the objective allows command maintenance in the smallest possible area of variation, which correspond to the "control" part of the process.

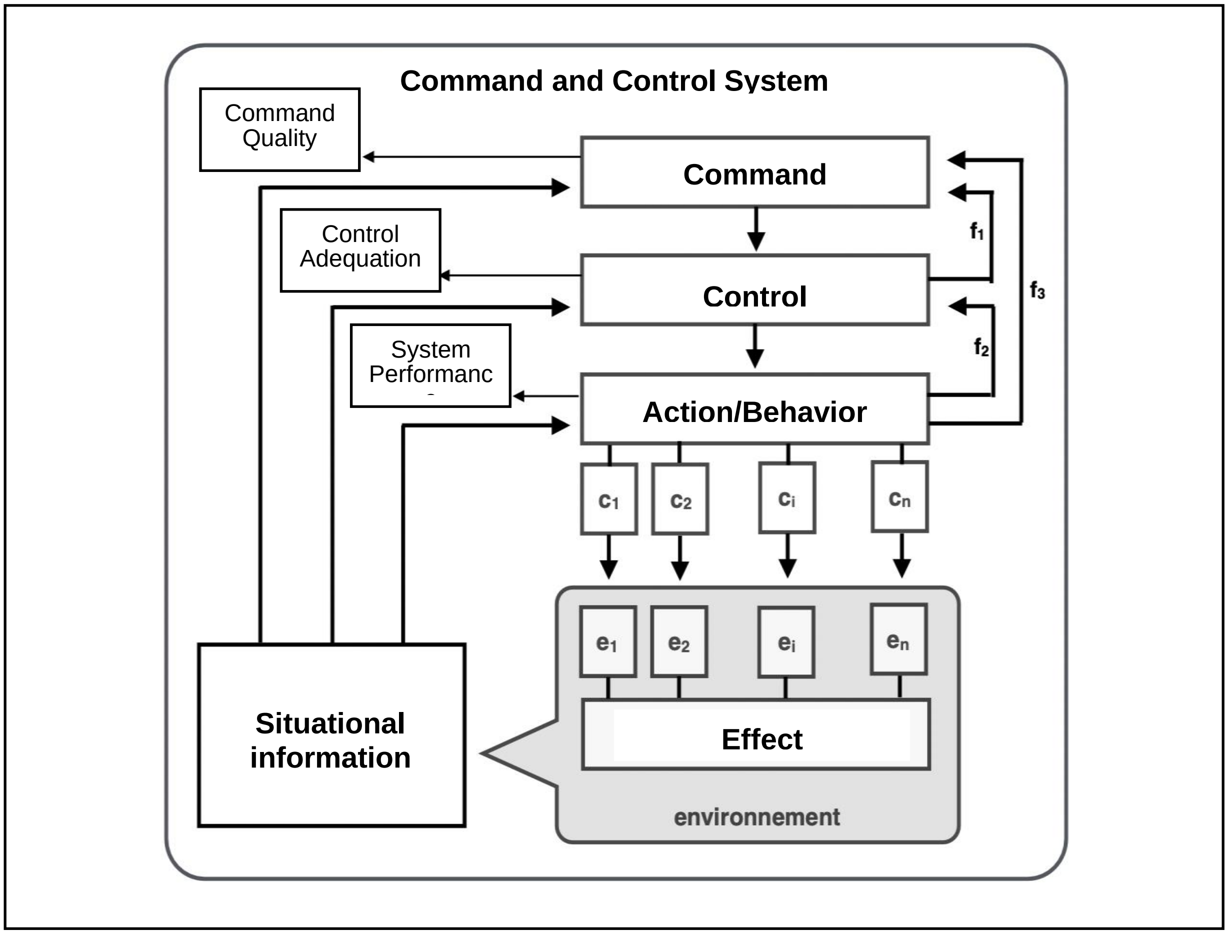
FIGURE 3
BASIC CYBERNETIC PRINCIPLE SHOWING THE COMMAND PART AND THE CONTROL PART OF THE ADJUSTMENT TO A DESIRED END STATE



We can easily understand C2 by returning to the principles of a simple cybernetic system and then gradually complicating it (Claverie & Desclaux, 2015, op. cit.). An example of a basic formal model of system regulation is that of the thermostat: it is a machine (now digital), equipped with sensors (thermometers) and an adjustment device (automatic level control) to adjust the temperature of a medium (system response, or behavior).

Heating corresponds to a first behavior and refrigeration to a second. The user of the device (the commander) imposes his decision (order) to achieve a desired effect (goal) thanks to the device. It is the evolution toward this effect that in return, and thanks to sensor information, triggers a behavior chosen from a finite range of varieties. Usually, refrigeration and heating controls are interrelated and can self-control each other to allow evolutionary learning, for increasing accuracy over time. A set of relationships makes it possible to communicate between the different stages, from the command to that of the control, then to that of behavior and to cause an effect on the environment (feedback). Each floor has a window of possibilities (degree of freedom) set by the program. It is already noted that for this simplest cybernetic system, two characteristics are unavoidable: the articulation of command and control for action according to the decision taken, and the widespread distribution of information. Thus, the command is so associated with the concept of control that the two words are now associated in the same locution: "command and control"; a bit like "pick and go," "rock and roll," "cash and carry" etc., which are forged on two distinct verbs but so associated in use that joint notion has supplanted the use of the simple words of which it is composed.

FIGURE 4
CONCEPTUAL MODEL OF A SYSTEM DEFINED BY "COMMAND-CONTROL-BEHAVIOR AND "FEEDBACK" COMPNENTS, AND MULTIPLE CONTROL LOOPS



Inspired by Alberts and Hayes (2006).

In a "formal automata," the commander level decides and the controller level has a certain freedom of choice (algorithm) in a fixed range of orders given to the effector who then acts directly on the medium (area of control). At any time, the controller informs the commander and the effector informs the controller and the commander. Everyone is also directly informed of the general state of the system from a sensor device (situational information) and feedback loops. The information contained in the system corresponds to the set of "command-control-behavior-effects" signals associated with all "feedbacks" (see details in Figure 3). Each system is, therefore, defined according to rules defining a basic conceptual model: command and control, behavior, and feedback.

This model has been the subject of multiple instantiations, whether for mechanical machines, energy machines, or informational machines. It is especially in the field of the latter that the application is most spectacular with the development of computers but also that of multiple modern electronic devices. Computers can connect to each other and operators become as nodes of operational networks interacting as part of a global project defined for the entire system. This system and its subsystems, sensors, sensors, transmitters, filters, amplifiers, analyzers, displays, etc. participate in the almost limitless production of new data that cannot be used without immense computing power. Whatever the collaborative information devices, they all today become data producers both for their own regulation and also to enrich specialized or generalist databases in a world of “big data” (C4ISR & Networks, 2015, op. cit.), contributing to a new form of “computational complexity” of computing and information (Cooper, 1994, op. cit.).

All these interconnected devices themselves have subsystems constituted on a similar model. Are they on several levels the elements of supersystems becoming “systems”? These devices have been the subject of “systems engineering” in recent years, which some call “complexity engineering” (Luzeaux and Ruault, 2008). In such a modular organization, modules include other modules of the same structure, responding to the characteristics of another form of so-called “dimensional” complexity. Each module and stage strives to maximize control quality characteristics, control adequacy, system performance, information relevance, and mission accuracy. The global system here illustrates the definition of a “complex artificial system” based on the principles of cybernetics.

The Military C2 in a Few Questions

The operative and instrumental component of C2 (C4ISR-TAR) is now well known, developed, and formalized effectively in many manuals, notes, and circulars. However, it can be seen that the theoretical part of C2 does not yet promote a simple and clear conception. Centers, laboratories, and research networks have been dedicated to the field in recent years. A vast body of knowledge is thus accessible today. However, there is no unified theory of C2; that is, there is no consensual science of C2.

Several attempts have taken place, resulting in more or less convincing results (Coakley, 1991). For the benefit of the advances, we must mention the excellent work of the CCRP (Command and Control Research Program) of the DoD, including that of Alberts and Hayes (2004). The ELICIT experimental program studies different parameters of C2 (2006) in simulated situations and is now used for simulation and training (Tossel et al., 2008; Rudy, 2011). Other initiatives are to be noted, especially with companies. The EXC3ITE simulation laboratory (Experimental Command, Control, Communications, and Intelligence Technology Environment) is an example (Yates et al., 1999). The activities of the Center for Analysis and Simulation for Air Operations Preparation (CASPOA) in Mont-Verdun (Lyon, FR) and those of the Centre of Excellence for Command and Control Support (C2-CoE) located in Eden (NL), both NATO reference centers, are part of this principle. They use simulation for C2 training of Air Force personnel or interoperability specialists. Each country, especially the West, which has a modern army, has such a training system and sometimes research centers. This type of pedagogy requires significant material and human resources, and significant investment by individuals in order to develop mastery in the absence of a comprehensive understanding of the complexity of command and operations management systems (operator, controller or coordinator levels, and commander).

Beyond applied research as permitted by previous devices in the direct field of civil or military applications, the challenge of research is to develop a set of fundamental principles that can form the basis of a command and control theory. The great difficulty of the domain lies in the complexity of C2 (Cooper, 1994, op. cit.; Olmedo, 2010; Woodcock, 1987). Its rationalization does not agree with instrumental decompositions and two dimensions can initially be differentiated. The first is ascending (Taylor & Snell, 1988) in terms of the number of levels and steps necessary to obtain a solution in which the C2 is organized from the assembly of the parts of a “construction set,” a kind of Lego of the C4ISR-TAR. This approach quickly collides with the barrier of the exponential explosion of managed information and creates, in particular by the inclusion of the variability attached to each brick and its different possibilities of articulation with the others. The human factor plays a central role in this variability and the individual characteristics of contributors to the system (constructive approach or bottom-up) and the nature of their interrelationships contribute to a combinatorial expansion. The approach of analyzing the system in a downward way (Levis & Athans, 1988), i.e., by breaking down the elements and defining the relationships between the elements, is a second approach that meets the principle of uncertainty due to sensitivity to initial conditions. It is confined to statistical descriptions (deductive approach or top-down), sometimes approximate, always reductive, and marked by unpredictability.

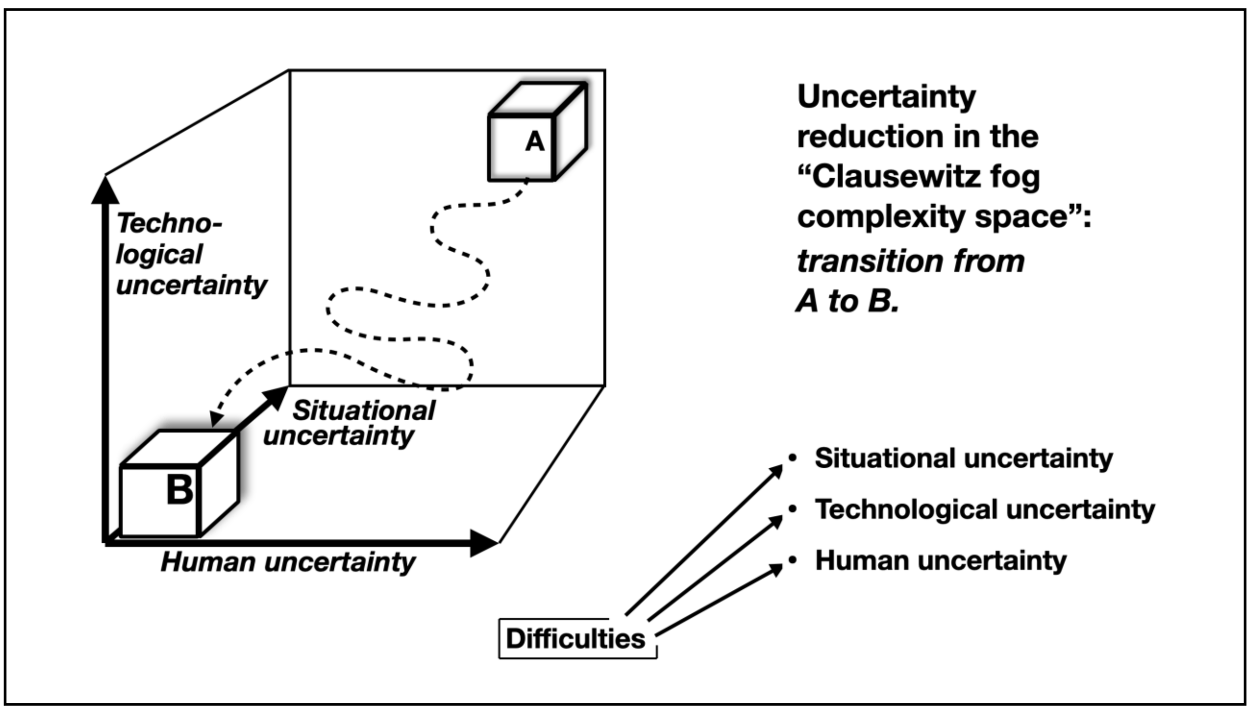
Another aspect of difficulty not to be neglected is the confusion caused by some technophiles or by conceptual simplification between the theoretical C2 and the instrumental applications of C4ISR. We believe that this confusion comes from the fact that C2 is a method and a machine for dealing with complexity, and that some specialists, especially operators, prefer to focus on the effective level of partial information processing by subsystems of which they become experts.

Levels of Complexity of C2

Of course, everything is not as simple as adjusting a thermostat or guiding a rocket to a target although already it's not as simple as that. The areas of use and intervention of C2 are infinitely more complex and security and military fields are areas of "hypercomplexity." Nevertheless, we can try to simplify to understand. At least three levels of complexity can be determined: complexity of uncertainty, dimensional complexity, and computational complexity (Cooper, 1994, op. cit.). The complexity due to the uncertainty of information is, for authors such as Levis and Athans (1988, op. cit.) the "great challenge" of C2. Recall the theorist of modern warfare, Clausewitz (1832), whose influence is known beyond the strictly military field in the humanities, political, and economic sciences, and according to which a large part of the information obtained in time of war is contradictory; an even greater part is false and most of it is by far quite doubtful.

These characters of uncertainty are themselves relative to dimensions of (1) uncertainty of the situation, (2) technological uncertainty, and (3) uncertainty of the human factor. C2 focuses on minimizing these three uncertainties and bringing the situation back to a state of relative mastering without which command and control is difficult to implement (see Figure 5: transition from situation A to situation B).

FIGURE 5
REDUCTION OF UNCERTAINTY IN "CLAUSEWITZ'S COMPLEXITY SPACE," WITH TRANSITION FROM COMPLEX SITUATION A TO A NEW BEST CONTROLLED SITUATION B



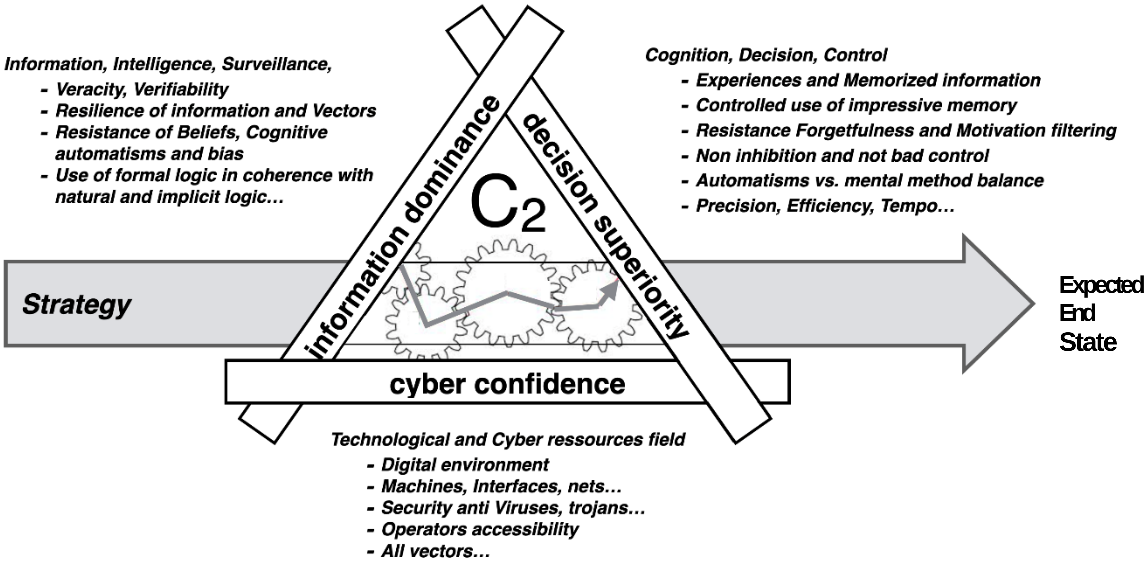
The maintenance of collection devices and their partial performance, the updating of the means of analysis, the fusion and mathematical approximations, the calculation limit of computers rounding their results (for example, exceeding the limit of microprocessors is known to result in potentially critical or even catastrophic computer errors), the need for reduction for an often immediate pictorial representation for operators themselves is sometimes diminished. If this type of uncertainty can be reduced by the evolution of technology, the improvement of calculation algorithms, and the development of more elaborate and safer cognitive engineering procedures, then we are constantly confronted on the one hand with an increase in equipment and their power, but also with an evolution of countermeasures and stealth of information sources. A major source of uncertainty is due to external human activities. Voluntary actions of parasitization and saturation of sensors, cyberattacks, or direct physical actions of degradation of sensors, networks, or decision and control centers are examples.

The enemy is often intelligent, active, and unpredictable. It has a vast repertoire of techniques aimed at producing uncertainty and all components of the system are likely to be victims of it. One of the goals of the system designer will be the robustness of the elements and networks: those of the user will favor that of procedures, the maintenance in operational condition of the devices, and their protection against physical or informational attacks. This is the one example of the trend toward the suppression of voice communication and its substitution by secure chats and forums using high-speed and robust links (Kometer, 2007). Intelligence enters this area by "cross-checking sources" and minimizing uncertainty while providing information that escapes certain traditional technologies.

The main source of human uncertainty is paradoxically internal; it is relative to the weaknesses of the actors in the system. The "human factor" is the most difficult to assess, understand, and control. It is also a prime target of cognitive warfare (Claverie & du Cluzel, 2022). It causes bias and errors that create uncertainty both at individual and group levels. This source is pernicious because it is often produced in good faith and, therefore, is likely to go unnoticed. It can relate to agents or decision-makers, perceptual biases, misrepresentation, or upward influences that modify the decision based on options taken at lower or higher levels etc. (Sage, 1981; Bushnell et al., 1988). Faced with the flood of information, different physical and contextual filters can reduce the amount of information provided to the decision-maker. Although this solution improves the quality of situational awareness and, therefore, the quality of the decision, Taylor and Snell (1988, op. cit.) showed that it is not the lack of quality information that is involved in inadequate decisions but rather the lack of attention and sufficient cognitive performance of the decision-maker. The proposed solution is to transfer the most workload to artificial intelligence and increase decision support programs. The data must, therefore, be synthesized and merged into globally intelligible information, and must be processed to generate contextual knowledge bases. The challenge of human engineering is precisely to understand and control the causes of uncertainty by working on the robustness of procedures, on representational sharing, on relational confidence in the control of error in complex systems (Strauch, 2007), and in the use of cognitive systems for increased cognition, decreased technological complexity, and a contextualization of complexity.

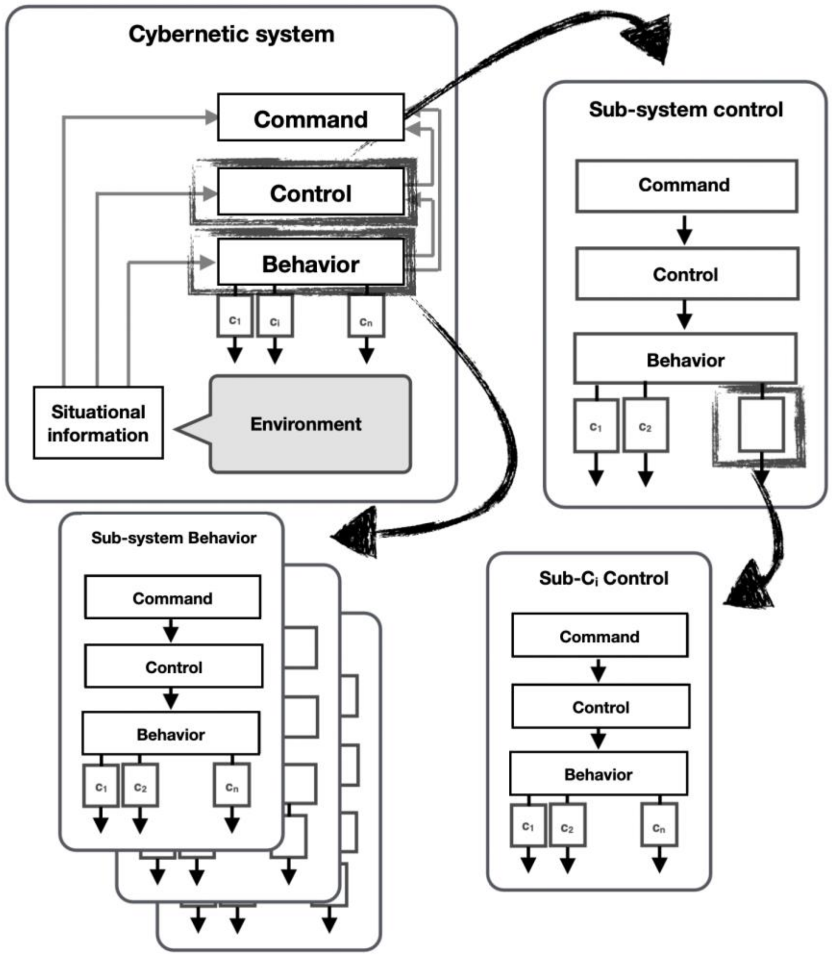
These three dimensions form the pillars of what is called the "C2 triangle" (Claverie & Desclaux, 2015, op. cit.). There is talk of the need for (1) information dominance, (2) cyber confidence, and (3) decision-making superiority. This triangle is the fundament of the "cognitive machine" of the "Command & Control" process (see Figure 6).

FIGURE 6
C2 TRIANGLE, WITH THE THREE ASPECT OF INFORMATION DOMINANCE, CYBER CONFIDENCE, AND DECISION SUPERIORITY



Dimensional complexity corresponds to the fact that a command and control system is cybernetics structured into a hierarchy of subsystems, each of which can itself consist of a cybernetic system in its own right and itself composed of subsystems etc. (see Figure 7). The cellular level can then be considered the human operator, itself being a cybernetic system composed of internal systems etc. However, there is mutual interaction between competing subsystems and an encompassing system. All processes managed or produced at different levels themselves generate multiple interactions and regulations, also interacting with each other. The number of cases to consider is increasing exponentially as each interface can generate considerable amounts of different messages. If each of them can be easily processed and analyzed in a simple way, then the fractal system as a whole exceeds the capacities of spontaneous understanding and representation, and modelling capabilities. Levis and Athans (1988, op. cit.) speak in this regard of the "curse of dimensionality," regretting that the engineering of traditional systems, where a problem is divided into simple levels, cannot be applied. Cooper (1994, op. cit.) notes in this regard a form of self-similarity, or similarity between levels. He suggests that the principle that each subsystem is made up of subsystems with the same cybernetic structure, and so on, meets the criteria of a complex structure (Woodcock, 1988).

FIGURE 7
MODEL FOR THE DECOMPOSITION OF ELEMENTS INTO "COMMAND-CONTROL-BEHAVIOR" CYBERNETIC SUBSYSTEMS ACCORDING TO THE PRINCIPLE OF SELF-SIMILARITY, A PRINCIPLE THAT IS A BASIS CHARACTER OF COMPLEXITY



The complexity of calculation is that encountered by structures managing large projects. The dimensions of speed, reliability, and computing power bring C2 and its immense amount of data into the world of "big data." This field, which is now of major interest by companies and institutions, has both sides of its interest and constraints (Cointot & Eychenne, 2014). Big data consists of all the data generated and collected continuously without a priori categorization, and whose volume is growing exponentially. They generate new uses, new strategies, and new challenges for those who have the IT means and algorithms necessary to process them. By reversing experimental science into a prospective approach, big data engages society, its companies, and institutions in the exploitation of data to fuel tomorrow's economic and military world (Babinet, 2015). Everyone agrees that those who master the exploitation of big data are the holders of tomorrow's techno-power. This exploitation begins, of course, with the mastery of sensors but also with the processing of open data, open source, and broadcast information (Alberts & Hayes, 2006, op. cit.). The numerical reason is now circumscribed by the "anthropology of exponential" (Claverie, 2019), obeying, for content, Moore's Law from a half a century ago that predicts the power of digital components. This exploitation opens up to "data mining" approximation algorithms and the debate on artificial intelligence.

AI techniques have long been used in different dimensions of C2: tactical planning aids (Akey et al., 1987), expert systems in battle management (Flynn & Senator, 1987), surveillance aids (Goubert & Desjouis, 1989), and, more generally, problem solving in uncertain environments (Andert, 1992). AI and statistical iconography are the basis for the necessary reification of the data. All the information given at each decision stage is a more or less faithful reflection of certain physical characteristics of the environment, the nature of events that occur there, and added artificial intelligence data. It allows each level to have a "certain consciousness" of the real. If the "data" are supposed to be descriptions, then they are interpreted and reach the commander only in a specular way. However, interpreted data is more or less questionable and C2's approach will then be to provide an inventory of it with immediate or delayed response algorithms according to selection criteria supported by necessary artificial intelligence metasystems.

In this context, the limits of computers as problem-solving tools can be determined according to two types (Taylor & Snell, 1988, op. cit.). "Calculable and programmable" problems are those that can be solved with current technology. This is the case with calculations for sorting algorithms or those using Fourier transform or any means of signal processing. In fact, these issues are only part of the problems concerned by C2. Other problems are "programmable and non-calculable." These are those for which algorithms require time, memory, or energy constraints too great for practical solutions. The theory of computer complexity raises the question of whether the answer to a problem can be given very effectively, effectively or, on the contrary, be unattainable in practice or theory (nondeterministic problems, for example). The qualification of the difficulty of intermediate levels between the two extremes is based on an estimate of computing times and computer memory needs. It is, therefore, both a question of hardware and software. Finally, some problems are not calculable. These are mainly those that concern the human factor, the imponderable, and the unpredictable, and are the subject of special procedures as long as they have been imagined by the designers of the programs or procedures.

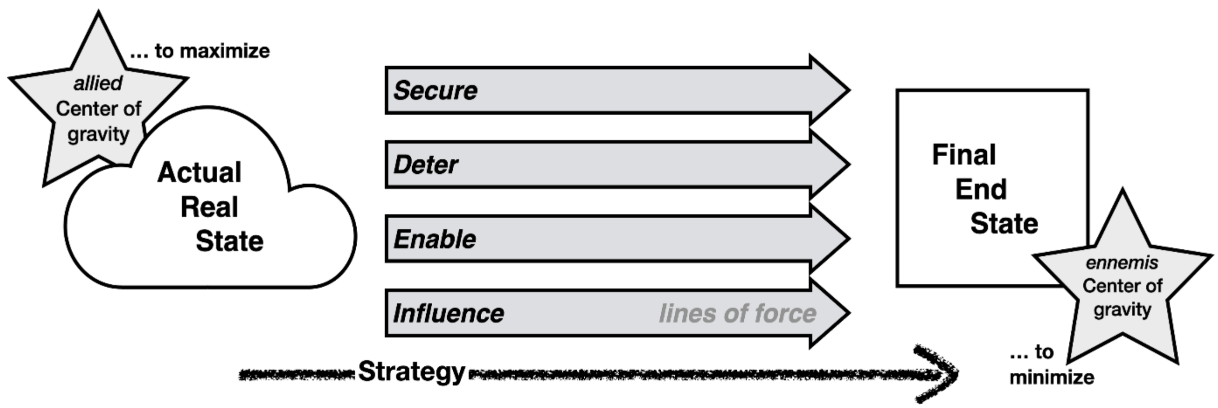
Theory of complexity establishes hierarchies or "complexity classes." However, the complexity of the operations to be carried out also has consequences for their concrete progress. This is the case with the energy consumption necessary for their realization, both to power computers and to cool them. This energy can vary considerably depending on the performance of the processes used to perform calculations according to the "Landauer principle" (Landauer, 1961; Moore, 2012). For example, it is known that "Power Usage Effectiveness" (PUE), which is the most used indicator to compare data center power consumption (Avelar et al., 2012), exceeds direct computing consumption up to 20% for the best energy performance of data centers. This means that for each kilowatt hour of electricity used by machines, it takes at least 1/10 additional kilowatt hours for storage, maintenance, cooling, etc., and 1/20 for security procedures. The expenses relating to soft security and, paradoxically, the necessary cost for the implementation, maintenance, and safety of the calculation, are not calculated. We can reasonably assume that it also evolves as the necessary power and the energy need, that is, exponentially.

C2 as a Synchrony of Complex Treatments

The C2 method consists in taking into account all problems and treating them as categories of problems. Each category is then treated by a specific sub-C2 and the global C2 becomes a kind of synthetic approach, like a musical score whose commander ensures harmony among the different lines to be played. It is then necessary to sectorize the areas of complexity by separating the areas into a score of "lines of force." These lines of force are predetermined, like musical instruments that contribute to the complete work, each for what they know and can do. The effect of C2 emerges from this synchrony of lines.

According to NATO doctrine, they traditionally concern four dimensions, "secure, deter, enable, influence" (Claverie & Desclaux, op. cit.), whose goal is to maximize the center of gravity of the actor, the commander, and his collaborators, and to minimize that of the opponent. It can be said that the strategy breaks down into lines of force, each in relation to the others, and each contributes to the weakness of obstacles and resistance on the path to the desired goal.

FIGURE 8
PRESENTATION OF THE STRATEGY: DOCTRINAL SCORE OF THE GLOBAL PATH OF THE STRATEGY IN FORCE LINES BY THE DIFFERENT DIMENTIONS OF COMPLEXITY



Each of these lines of force has technical, energy, systemic, and human costs. These cumulative investments, including control of the carbon footprint and investment in high technology and qualified specialists, are all factors that gradually move C2 away from the capacities of small and medium-sized companies, and of certain nations, which must then delegate command and control to great consortiums or major alliances.

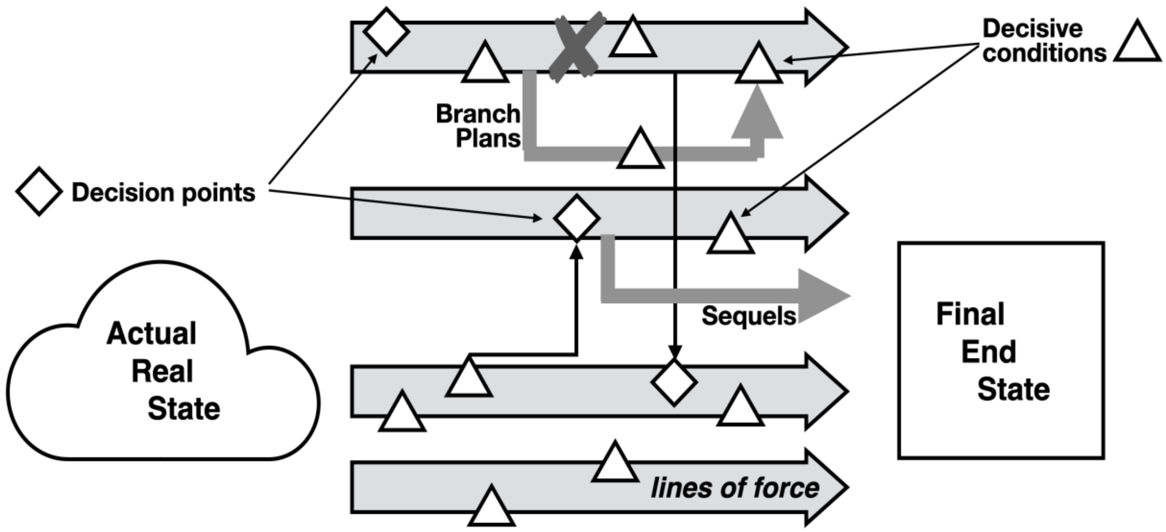
An Orchestral Score to Accompany Complexity: The Human Conductor

One of the main obstacles to the design, management, and application of C2 is, therefore, the multiplication of the lines of force. Historically resulting from accumulation procedures evolving both at the pace of technological developments and the balance between safety issues and real, human, ecological, and financial costs, the technical and procedural declination of the C4ISR today meets the limits of these fields. The complexity of systems is one reality while its dynamic evolution is another and the observation of its care and control by man becomes a necessary constraint on the use of large-scale technological devices. C2 does not escape this and exceeding these limits depends on humans.

The place of humans in the management of complexity is reviewed by some authors. In particular, ergonomists consider that complexity is a form of enemy of man, a kind of barrier or glass wall that should be removed. This perspective is naive, based on the best intentions and focuses on both the issues of protection of the operators, the improvement of working conditions, and well-being in its fulfillment.However, this movement is not free of defects. It makes it easy to make a certain form of lock-in in competition between scalable technologies or even between rival or suppletive technologies. This observation is associated with the theory of "path dependency" (David, 1985). According to this theory, we often choose less effective solutions because they are more economical to maintain than to imagine, develop, and finally adopt a change. This "adaptation by continuation," therefore, depends not only on the human cost of change for agents but also on the economic cost to the system or on the cost of procedural, doctrinal, or legal evolution.

Some authors, particularly those inspired by the systemic current of "human factor," consider it necessary to adapt to complexity and its inevitable evolution in technological systems. For them, complexity is not a wall, handicap, or limit, but rather more a wave that we do not stop and that should negotiate by favoring aptitude, performance, and material or strategic help to surf and move forward with it. The relationship of complex technological systems to man is then expressed in several dimensions. First and foremost, and globally, the greater the uncertainties, ambiguities, and strangeness the more paradoxically necessary human intervention becomes, and the more complexity increases, the more central the role of man becomes. Second, on the material register, the more that decision-making time decreases the greater the likelihood of a human decision outside of procedures or means of artificial assistance. The more fallible these available aids the more often man is called upon to fill the gaps in the system (Smith, 2006) and, therefore, to produce errors.

FIGURE 9
STRUCTURE OF THE "OPERATIONAL DESIGN" OF THE C2



To overcome this limitation, the C2 domain develops today performative research oriented toward the mastery of the complexity of war, which is known to be dynamic and self-creating of its own increase. This cannot be done without the means of training, modelling, data analysis, and decision support, or even delegation to increasing artificial intelligence processes. It is this path that is promoted today for the efficiency of C2, with an increase in dominance information, accompanied by statistical and big data techniques, analytics, natural language processing, 3D vision, and immersive techniques etc. by reducing the complexity of machines while increasing their network performance, resilience, and security, and increasing and promoting decision-making superiority through artificial intelligence, machine and deep learning programs, and a lot of collaborative tools for increasing effectiveness. These research efforts develop the idea of an "operational design" according to the times and durations of the war (see Figure 9) whereby time synchronization is ensured by the commander and his staff.

Therefore, C2 can be considered as an anthropotechnical system of human–artifact collaboration, used to manage complex sets constituting the overall complexity of a strategic situation.

CONCLUSION

The support of complexity by man immersed in major technological systems such as those managed by C2 is based on three components: informational dominance, cyber confidence, and decision-making superiority. The more technology and its interfaces are simplified while presenting increasingly relevant strategic, reliable, and secure information, the more uncertainties and ambiguities are minimized.. Moreover, the term clarification of information may be preferred to the more ambiguous term simplification of information.

This results in a reduction in the necessary rate of human intervention and a reduction in the constraints of control ergonomics and correction ergonomics. Then, greater contextualization delimits the complexity of the problem and a more proper representation of reality is favored. Human intervention in the loop will be all the less necessary for verification, control, and adjustment procedures. Finally, the increase in performance due to the introduction of decision-making strategies, human increase, and artificial intelligence provides fast and effective support to free-up time for decision-making. In this way, the probability of a correct decision increases and the operator will be less often in a situation of ultimate recourse in critical situations. Finally, networks allow the dissemination of explainable decision-making information throughout the system, where everyone can understand, feel concerned and, in turn, contribute to increasing information and facilitating decision-making.

In this context, the transformation of hierarchies inherited from the Cold War now makes it possible to address agility strategies in defense (Desclaux, 2006, op. cit.), as well as in major industrial or security complexes. Plasticity and the structural, functional, and strategic evolution of the conflicts of the 21st century are constraints that C2 must assume. The concept of "power to the edge" has been promoted in recent years by the DoD. It consists of valuing peer-to-peer dissemination of information ("bright dissemination") and interaction with decision-making at the most competent and timely level ("unconstrained interaction among the actors") (Alberts & Hayes, 2004, 2006, op. cit.). These dimensions are accomplished within the general objectives of a modular command that assumes the directions, support, and security constraints and training of the different levels of C2 by implementing both the clarification of information, its contextualization in complexity, and the increase of human capabilities through digital technology.

All this requires an important research effort that the major nations are now assuming, particularly those of the Atlantic Alliance in the IST (Information Systems Technology) panel of NATO's STO (Science and Technology Organization).

ACKNOWLEDGEMENT

Translated & edited by American Publishing Services (https://americanpublishingservices.com/).

REFERENCES

Akey, M., Dunkelberger K., & Erdman, R.C. (1987). Case studies in tactical decision support systems. In S.J. Andriole, & J.L. Boyes (Eds.), *Artificial Intelligence and National Defense* (pp. 57–65). Washington (DC): AFCEA International Press (Armed Forces Communications and Electronics Association).

Alberts, D.S., & Hayes, R.E. (2004). *Power to the Edge: Command, control, in the information age*. Information Age Transformation Series. Washington (DC): US Department of Defense CCRP Publication Series.

Alberts, D.S., & Hayes, R.E. (2006). *Understanding Command and Control*. Washington (DC): US Department of Defense CCRP Publication Series.

Andert, E.P. (1992). Integrated knowledge-based system design and validation for solving problems in uncertain environments. *International Journal of Man-Machine Studies*, *36*(2), 357–373.

Avelar, V., Azevedo D., & French, A. (Eds.) (2012). *PUE: A Comprehensive Examination of the Metric.* Beaverton (OR): The Green Grid Library.

Babinet, G. (2015). *Big data: Penser l'Homme et le Monde Autrement*. Paris (FR): Le Passeur Éditeur.

Boyes, J.L., & Andriole, S. (Eds.) (1988). *Principles of Command and Control*. Washington (DC): AFCEA International Press (Armed Forces Communications and Electronics Association).

Builder, C.H., Bankes, S.C., & Nordin R. (1999). *Command Concepts: A theory derived from the practice of Command and Control*. Santa Monica (CA): RAND National Defense Research Institute.

Bushnell, L.G., Serfaty, D., & Kleinman, D.L. (1988). Team information processing: A normative-descriptive approach. In S.E. Johnson & A.H. Levis (Eds.), *Science of Command and Control: coping with uncertainty* (pp. 62–72). Washington (DC, USA): AFCEA International Press (Armed Forces Communications and Electronics Association).

Clausewitz, (Von) C. (1832). *On War* (traduction 1989 M. Howard & P. Paret). Princeton (NJ): Princeton University Press.

Claverie, B. (2005). *Cognitique: Science et pratique des relations à la machine à penser*. Paris: L'Harmattan.
Claverie, B. (2019). Dynamiques exponentielles et naturalité de l'intelligence artificielle. *Hermes*, *85*, 189–200.
Claverie B., & Desclaux, G. (2015a). La cybernétique: commande, contrôle et comportement dans la gestion des systèmes d'information et de communication. *Hermes*, *71*, 72–79. Paris (FR): CNRS Editions.
Claverie, B., & Desclaux, G. (2015b). C2 et Cyber. *Penser Les Ailes Françaises*, *32*, 60–68.
Claverie, B., & Du Cluzel, F. (2022). Cognitive Warfare: The Advent of the Concept of "Cognitics" in the Field of Warfare. In B. Claverie, B. Prebot, N. Buchler, & F. Du Cluzel (Eds.), *Cognitive Warfare: The Future of Cognitive Dominance*. Neuilly (FR): NATO-STO Collaboration Support Office, 2, 1–7.
Claverie, B., Prebot, B., Buchler, N., & Du Cluzel, F. (Eds.) *Cognitive Warfare: The Future of Cognitive Dominance*. Neuilly: NATO-STO Collaboration Support Office.
Coakley, T.P. (Ed.). (1991). *C3I: Issues of Command and Control*. Washington (DC): National Defense University Press.
Cointot, J.C., & Eychenne, Y. (2014). *La Révolution Big Data: les Données au coeur de la Transformation de l'Entreprise*. Paris (FR): Dunod Editions.
Collective. (2006). *ELICIT Report, Experiments in Command and Control within Edge Organizations*. Command and Control Research Program, Washington (DC): US Department of Defense CCRP Publication Series.
Collective. (2015). *C4ISR&Networks. Managing massive data*. Washington (DC): Air Force Cyber Initiatives. White paper.
Collective: Joint Chiefs of Staff DoD. (2008). *Department Of Defense Dictionary of Military and Associated Terms.* Joint Publication 1-02, Washington (DC): Government Printing Office (GPO), GPO Bookstore.
Cooper, C. (1994). Complexity in C3I systems. In D. Green & T. Bossomaier (Eds.) *Complex systems: from biology to computation* (pp. 223–231). Amsterdam (NL): IOS Press.
Couffignal, L. (1963). *La Cybernétique*. Paris (FR): Presses Universitaires de France.
David, P.A. (1985). Clio and the economics of QWERTY. *American Economic Review*, *75*(2), 332–337.
Dayan, M. (1966). *Diary of the Sinai Campaign*. London (UK): Weidenfeld & Nicolson.
Desclaux, G. (2006). *Transforming JC Lisbon*. Tailored Task Organized DJTF Headquarter Structure. Lisbonne (PT): NATO. *White paper.*
Flynn, J.P., & Senator T.E. (1987). DARPA naval battle management applications. In S.J. Andriole & J.L. Boyes (Eds.), *Artificial Intelligence and National Defence* (pp. 66–82). Washington (DC): AFCEA International Press (Armed Forces Communications and Electronics Association).
Goubert, M., & Desjouis, M. (1989), Using artificial intelligence for battlefield surveillance. *Signal*, *10*, 69–73.
Joergensen, F.D., Larsen, P.G., & Stadtmueller, J.M. (2005). Untangling technology debates on information sharing and interoperability. *Proceedings of the Military Communications Conference*. MILCOM 2005. Atlantic City (NJ): October 17–20, 2005. IEEE CECOM, 4, 2333–2338.
Kometer, M.W. (2007). *Command in Air War: Centralized versus Decentralized Control of Combat Airpower.* Montgomery (AL): Air University Press.
Landauer, R. (1961). Irreversibility and heat generation in the computing process. *IBM Journal of Research and Development*, *5*(3), 183–191.
Larsen, P.G. (2006). Coalition C2 Interoperability Challenges. Proceedings of the *11th. International Command and Control Research and Technology Symposium* (ICCRTS-11). Cambridge (UK), September 26–28, 2006.
Le Roy, F. (1997). De l'utilisation des doctrines militaires dans le domaine de l'entreprise. *Annales des Mines, Gérer et Comprendre*, *47*, 89–96.

Levis, A.H., & Athans, M. (1988). The quest for a C3 theory: dreams and realities. In S.E. Johnson & A.H. Levis (Eds.), *Science of Command and Control: Coping with uncertainty* (pp. 4–9). Washington (DC): AFCEA International Press (Armed Forces Communications and Electronics Association).

Luzeaux, D., & Ruault, J.R. (2008). *Systèmes de systèmes*. Paris (FR): Hermes Sciences.

Moore, S.K. (2012). Computing Power Limit Demonstrated. *Spectrum IEEE*, *49*(5), 14–16.

Olmedo, E. (2010). Complexity and chaos in organisations: Complex management. *International Journal of Complexity in Leadership and Management*, *1*(1) 72–82.

Rudy, M. (2006). Pedagogical use of ELICIT for Leadership Training: Survey and Recommendations. *Proceedings of the 16th International Command & Control Research & Technology Symposium* (ICCRTS-16). Quebec (CA), June 21–23, 2011.

Sage, A.P. (1981). Behavioral and organizational considerations in the design of information systems and processes for planning and decision support. *IEEE Transactions on Systems, Man, and Cybernetics*, *SMC-11*, 640–678.

Smith, E.A. (2006). Complexity, Networking, and Effects-based Approaches to Operations. *Information Age Transformation Series*. Washington (DC): US Department of Defense CCRP Publication Series.

Steinbuch, K. (1957). *Informatik: Automatische Informationsverarbeitung*. Berlin (DE): SEG-Nachrichten Nr4: S, 171.

Strauch, B. (2007). *Investigating Human Error: Incidents, Accidents, and Complex Systems*. Aldershot (UK): Ashgate.

Taylor, E.C., & Snell, D.J. (1988). Artificial intelligence in command and control. *Signal*, *4*, 25–29.

Tossel, C.C., Splawn, J.C., Denning, T.D., & Bennet, W.R. (2008). The Effectiveness of gaming Technology in Command and Control training. *Proceedings of the 21th American Psychology Association Annual Technical Symposium: Distributed Cognition: Teams, Technology, Family, and the Individual.* Fairfax (VA), March 6–7, 2008.

Warden, J. (1995). Air Theory for the 21st century. In B.R. Schneider, & L.E. Grinter (Eds.) *Battlefield of the Future: 21st Century Warfare Issues* (pp. 103–123). Montgomery (AL): Air University Press.

Wee, C.H., Lee, K.S., & Bambang, W.H. (1991). *Sun Tzu: War and Management.* Singapore (SG): Addison-Wesley.

Woodcock, A.E.R. (1987). Catastrophes, Chaos, and C3I. *Proceedings of the IEEE 2nd International Conference on C2 information Technology (CIT) and Management Information Systems*, *275*, 31–37. Londres (UK): The Institution of Electrical Engineers. May 3-5, 1987. IEEE Conference Pub.

Woodcock, A.E.R. (1988). Indications and warnings as an input to the C3 process. In J.L. Boyes, & S.J. Andriole (Eds.), *Science of Command and Control: coping with uncertainty* (pp. 32–47). Washington (DC): AFCEA International Press (Armed Forces Communications and Electronics Association).

Yates, A.J., Vernik, R., Maheswaran, N., & Allwright, A.M. (1999). *Systems Characterisation and Modelling Approaches for C3I*. Canberra (AU): Australia's Defence Science and Technology Organisation (ADSTO - ADoD). *White paper.*