Defence Research and Development Canada
Recherche et développement pour la défense Canada

DEFENCE R&D DÉFENSE

The M-OODA: Modelling of the OODA loop as a modular functional system

R. Breton
R. Rousseau
DRDC Valcartier

Defence R&D Canada – Valcartier
Technical Memorandum
DRDC Valcartier TM 2008-130
September 2008

Canada

The M-OODA: Modelling of the OODA loop as a modular functional system

R. Breton
R. Rousseau
DRDC Valcartier

Defence R&D Canada – Valcartier

Technical Memorandum
DRDC Valcartier TM 2008-130
September 2008

Principal Author

Original signed by Richard Breton

Richard Breton

Defence Scientist / C2 Decision Support System

Approved by

Original signed by Éloi Bossé

Éloi Bossé

Section Head / C2 Decision Support System

Approved for release by

Original signed by Christian Carrier

Christian Carrier

Chief Scientist

This work has been carried out under the 11bu work unit.

Abstract

The objective of the present document is to present a modified version of the OODA loop, the M-OODA. For the M-OODA loop to remain a useful tool in the context of documents defining the armed forces doctrine on C2, any modification has to keep explicit the high-level representation typical of the OODA loop, while accommodating dynamic and control concepts. The M-OODA incorporates explicit control and flow components more in line with the current understanding of military C2. It is based on a modular structure in which a module operates as a simple control system. A module is a task-goal directed activity formed of three core components (Process, State, and Control). A number of modules are structured in an OODA loop fashion and interconnected by feed-forward and feedback loops. The M-OODA model provides a compromise between that high level view of C2 decision-making, valued in military documents, and an expansion accommodating the basic C2 functions on information handling, processing, communicating and the coordination and direction in C2.

Résumé

L’objectif de ce document est de présenter une version modifiée de la boucle OODA, la boucle M-OODA. Afin de préserver l’utilité de la boucle OODA pour représenter le processus décisionnel en C2, toute modification apportée doit préserver les bénéfices de la représentation des quatre grandes phases du cycle décisionnel tout en apportant plus de détails sur la nature dynamique de la prise de décision et les notions de contrôle. La boucle M-OODA inclut des composantes permettant de représenter les notions de contrôle et de transfert d’information (flux) plus conforme à la compréhension actuelle de C2. Elle est basée sur une structure modulaire dans laquelle un module, dirigé par les buts, fonctionne comme étant un système simple de contrôle. Pour représenter le cycle décisionnel en C2, des modules sont structurés selon la représentation classique de la boucle OODA. Ces modules, formés de trois composantes (Processus, État, Contrôle), sont interconnectés par des boucles de rétroaction et de transmission. Le modèle de la boucle M-OODA offre un bon outil de représentation du cycle décisionnel en C2, tout en fournissant plus de détails sur les fonctions de base en C2, telles que la manipulation d’information, son processus, et les principes de communication, coordination et direction en C2.

This page intentionally left blank.

Executive summary

The M-OODA: Modelling of the OODA loop as a modular functional system

Richard Breton; Robert Rousseau; DRDC Valcartier TM 2008-130; Defence R&D Canada – Valcartier; September 2008.

Introduction or background:

Despite several critics, the simple high-level representation of concepts in the classical model of the OODA loop is still favoured in military documents to represent C2 decision-making activities. Problems occur with the OODA loop when this model is taken as a descriptive decision-making model and then used to support the development of training programs and the design of support systems. Rapidly, more complex C2 decision-making models that include the dynamic dimension and notions of control inherent to C2 environments are proposed. The representation of these concepts, dimensions and notions within the C2 decision-making model comes with the cost of increasing significantly the level of complexity of the representation. The objective of the present document is to present a modified version of the OODA loop, the M-OODA.

Results:

The M-OODA is built in keeping with three principles. First, it adopts a modular architecture in which each process of the OODA loop is represented as a generic module structured around three components: Process, State and, Control. The Process represents a cognitive activity supporting the goal accomplishment of the module. The State represents the result of the goal-directed cognitive activity of the module (Process). It is based on the nature of the Process and the inputs (Data). The criteria-based Control component is a flow control function gating the delivery of the output to other modules and enabling iterations of the process within the module. Control can interrupt, iterate the process or exercise no gating function depending on the mode of operation required. It can accept a given level of state quality (uncertainty level) depending on task-goal criteria. Second, it incorporates explicit control elements within and across modules enabling a bi-directional data/information flow between modules. It also includes a feedback loop within each module. These explicit control and flow components are more in line with the current understanding of military C2. Third, modules are seen as building block. These building blocks are interconnected with feedback and feed-forward feedback loop to produce a model representing the activities included in C2 decision cycle.

Significance:

The M-OODA accommodates adaptability and flexibility inherent to dynamic and networked systems by including a distributed control function and explicit feedback and feed-forward loops. The modular structure provides a way to represent the ability to reconfigure forces and thus providing force agility. The M-OODA loop is a simple adaptive network of modules. The control nodes with the feedback/feedforward loops make the M-OODA loop sensitive to time pressure and requests from higher-level processes for specific information. The control component also serves the function of mapping the demands from other modules to the reality of a given module.

Then, the M-OODA loop keeps its valued high-level representation while accommodating dynamic adjustments compatible with C requirements.

Future plans:

The M-OODA loop framework will be used to develop a cognitive version of the OODA loop (the C-OODA loop) that will increase considerably the cognitive granularity of the model. The objective will be to support the identification of design requirements for decision support. Also, the M-OODA framework will be used to develop a team version of the OODA loop (the T-OODA loop) that will represent the concepts related to teamwork in C2 environments.

Sommaire

The M-OODA: Modelling of the OODA loop as a modular functional system

Richard Breton; Robert Rousseau; DRDC Valcartier TM 2008-130; R & D pour la défense Canada – Valcartier; septembre 2008.

Introduction ou contexte:

En dépit de plusieurs critiques, la représentation simpliste de la boucle OODA est toujours grandement utilisée dans les documents militaires afin de représenter le processus décisionnel en C2. Toutefois, les problèmes surviennent avec la boucle OODA lorsque cette dernière est considérée comme un modèle descriptif de la prise de décision pouvant soutenir le développement de programmes d'entraînement ou le design de systèmes d'aide à la décision. Rapidement, des modèles de prise de décision en C2 incluant les dimensions dynamiques de l'environnement et les notions de contrôle inhérentes au C2 sont proposés. La représentation de ces concepts, dimensions et notions dans ces modèles vient au prix de l'augmentation significative de la complexité de la représentation. L'objectif de ce document est de suggérer une version modifiée de la boucle OODA, la boucle M-OODA.

Résultats:

La boucle M-OODA est construite selon trois principes. Premièrement, elle adopte une architecture modulaire dans laquelle chaque processus de la boucle OODA est représenté dans un module générique structuré selon trois composantes de bases: Processus, État et Contrôle. Le Processus représente une activité cognitive supportant l'accomplissement du but du module. L'État représente le résultat de l'activité cognitive orientée-but du module. L'État est basé sur la nature de Processus et des entrées (données). La composante de Contrôle basée sur des critères est une fonction contrôlant le flux informationnel entre les modules et contrôlant les processus d'itérations permettant l'atteinte de critères de qualité et temporels. La composante de Contrôle peut interrompre, permettre d'autres itérations, ou transmettre l'information à d'autres modules selon la situation. Elle peut permettre un certain niveau de qualité de l'État (niveau d'incertitude) dépendamment des critères associés aux buts de la tâche. Deuxièmement, la M-OODA incorpore des éléments de contrôle intra- et inter-modules permettant le transfert bidirectionnel d'information entre les modules. Le modèle inclut également des boucles de rétroaction à l'intérieur de chaque module. Ces composantes de contrôle et de flux informationnel sont plus en conformité avec la compréhension actuelle des environnements militaires de C2. Troisièmement, les modules sont considérés comme étant des blocs de construction interconnectés avec des boucles de rétroaction et de transfert d'information afin de produire un modèle représentant les activités du cycle décisionnel de C2.

Importance: La M-OODA combine les principes d'adaptabilité et flexibilité inhérents aux systèmes dynamiques et réseautés en incluant une fonction distribuée de contrôle et des boucles explicites de rétroactions et de transfert d'information. La structure modulaire fournit une façon de représenter l'habileté à reconfigurer les forces et ainsi fournir une certaine agilité des forces. La boucle M-OODA est un simple réseau adaptatif de modules. La composante de contrôle avec les boucles de rétroaction et de transfert d'information rend la boucle M-OODA sensible aux

contraintes de pression temporelle et les réquisitions d'informations spécifiques de niveaux de processus supérieurs. La composante de contrôle sert également de fonction d'appariement entre les demandes de la part des autres modules et la réalité du présent module. Ainsi, la boucle M-OODA garde son représentation simple et de haut niveau qui est prisée dans les documents militaires tout en accommodant les ajustements dyamiques compatibles avec les requis liés au C2.

Perspectives:

Le contexte théorique de la M-OODA sera utilisé afin de développer une version cognitive de la boucle OODA (la boucle C-OODA) qui augmentera considérablement son niveau de granularité cognitive. L'objectif poursuivit par le développement de ce modèle est de soutenir l'identification de besoins en design pour l'aide à la décision. Aussi, ce contexte théorique sera employé au développement d'une version de la boucle OODA (la boucle T-OODA) abordant les concepts liés au travail en équipe dans les environnements de C2.

Table of contents

List of figures

List of tables

1 Introduction

Models are critical for the improvement of the execution of Command and Control (C2) activities. Models are contributing to the design of support tools and training efforts and may also influence task and team reorganization. The efforts at providing an acceptable model of decision-making in C2 have proven to be an enduring task. Repeated attempts at modeling C2 reflect the importance of such modeling for understanding the C2 task and its characteristics.

In addition to influence the design of support tools and the development of training programs, models are used for communication purpose between different communities (i.e. scientists and military). Communities need to agree upon a given model that reflects the task execution in the environment. However, problems with modelling often come from the level of complexity of the representation. To represent a complex task, models need to include several concepts interconnected together often resulting in very complex model architecture. While realistic, such complex representation may be useless for communication activities.

While complex models may provide sufficient detail to influence the design of support systems and training programs, simple task representation may be favoured to gather different communities around a specific task understanding. The best example is probably the case of the OODA [1] (Observe-Orient-Decide-Act) loop presented in Figure 1.

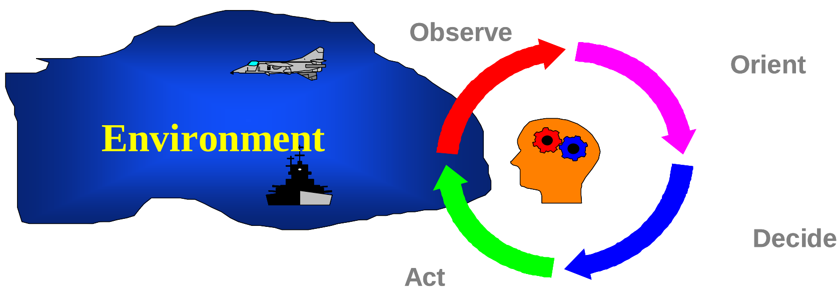

Figure 1: The classical model of the OODA loop

C2 can be seen as a control task in which decision-making is continuous [2]. It comprises a number of sub-tasks ranging from perception to action (e.g. Rasmussen's decision ladder; [3]). The OODA loop in itself can be labeled a simple control system as described by Jagacinski and Flach [4].

1.1 The OODA loop to represent military C2 decision cycle

In most military documents, the OODA loop is often referred to as a simple representation of control processes. Within military C2, U.S. Army Field Manual (AFM 6.0, in [5]) defines control as a regulation of forces and systems to achieve mission goals in accordance with the commander's intent. AFM 6.0 considers information as the most important element of control since it transforms data into meaning. Control is further described in U.S. Air Force doctrine document (AFDD 2-8, in [6]), as a set of processes for planning, directing and coordinating. In

AFDD 2-5 on information, control is defined as the processes by which commanders plan and guide operations. The commander's intent should specify the goal priorities and acceptable risks. Control operates through feedback for planning and directing purposes.

For one, AFDD 2-5 uses the OODA loop model as the basic set of processes describing a commander's decision-making capability. In the U.S. Navy doctrine document (NDP 6, in [7]) on naval C2, the OODA loop is given a central position as the basis for describing the Decision-Execution cycle in C2. Finally, US Army FM 6.0 considers the OODA loop to be a valuable tool for illustrating a commander's decision-making processes, albeit admittedly simplistic.

1.2 The OODA to model the military C2 decision cycle

The OODA loop is often described as a descriptive model of C2 decision cycle (see [8, 9]). Descriptive models need to include a more psychologically valid description of the processes involved in a decision-making task. A good descriptive model will reflect the decision-making processes of the commander and the C2 team. It provides a description that "makes sense". It is very flexible and can take into account most constraints that are typical of an operational setting. Then, if the classical version of the OODA loop is taken as a descriptive model of C2 decision-making process, it presents several flaws:

1. It has no representation of the feedback loops needed to effectively model dynamic decision-making.

2. It is a very high-level representation with abstract concepts that do not provide the kind of detail needed for the OODA loop to be used as an analytical tool for improving decision-making and influencing design of support tools.

3. It is a strict sequential model with a single entry point (Observe) and its representation suggests a single sequence of processes (O-O-D-A) that cannot adapt to different levels of expertise in decision-making and to the diverse task context existing in real tasks.

Nevertheless the arguments against the OODA loop model, the loop has always been very popular and frequently used as a descriptive model of decision-making in C2. On the one hand, our position is that given the current understanding of the control component of C2, and the necessity for C2 systems to adapt to the commander's information requirements following mission objectives and situational constraints, the classical form of the OODA loop lacks the power required to give a more adequate representation of C2 decision-making.

On the other hand, despite its limitations, this model is still used to represent C2 decision-making activities. Its popularity is largely due to its simplistic representation that captures important aspect of C2. Hence, it is our opinion that while providing alternative to accommodate dynamic and control concepts, any descriptive C2 model must keep explicit the four high-level processes represented in the loop to remain a useful tool in the context of documents defining the armed forces doctrine in C2. The objective of this document is to present a modelling approach used to develop a C2 decision-making model that provides sufficient level of detail to influence the design of support systems and training programs and keeps its representation level as simple as possible. Historically, many OODA alternatives and C2 decision cycle models have been proposed to reduce the limitations related to the loop modelling. The next section presents these models.

1.3 Other C2 decision process models

1.3.1 The extended OODA loop

An extended OODA loop, proposed by Fadok, Boyd & Warden [10] has been developed. As shown in Figure 2, the Orient process benefits the most from the extension. It is exploded into a number of factors. Furthermore, one can readily see explicit data feedback and feed forward loops extending from the Orient process. These loops make the Orient process a central contributor for guidance of the early and late processes. The other two processes also send feedback to the Observe process. While the content of the Orient process is made more explicit, no new processes are included in the loop. As it is often the case in modeling, while the extended model is more representative of decision-making, it becomes more complicated and, consequently, less useful for communication purposes. For instance, the factors included in the Orient process are very diverse and in some cases difficult to estimate, as it is the case, for the "Genetic Heritage" factor.

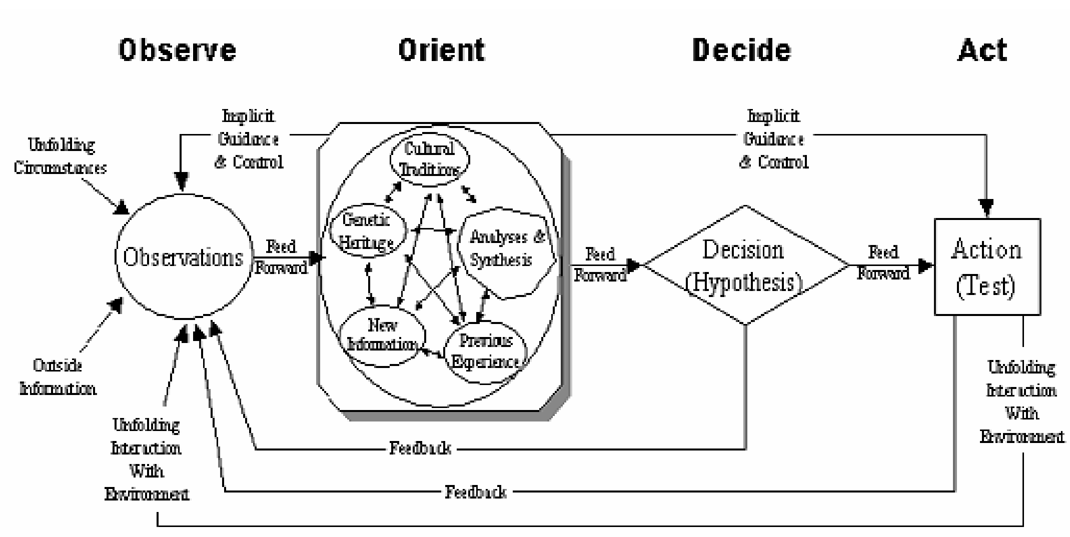

Figure 2: The extended OODA loop [10]

1.3.2 The iterative OODA loop

Breton & Bossé [11] also acknowledge the need to adjust the OODA loop to the dynamic aspect of decision-making. They propose a version of the OODA loop that includes an iterative process between the Observe and the Orient phases (see Figure 3). Again, it is the Orient process that is the target of the changes in the loop.

Breton & Bossé are more explicit concerning the nature of the feedback they include in the loop. It is a control loop enabling iterations of the Observe process. This iterative process is controlled by two criteria, which are the time constraint and the level of uncertainty. The iterative process is interrupted when the time available for analysis is elapsed or when an acceptable level of uncertainty is reached. Then, the Decide process is activated and the selected course of actions is implemented in the Act process.

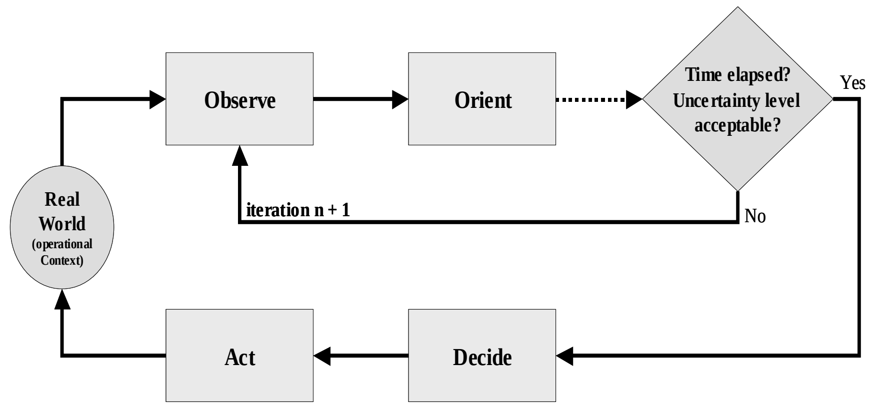

Figure 3: The iterative version of the OODA loop [11]

While Breton & Bossé provide a more formal definition of control within the OODA loop processes, the simplistic representation does not increase the level of detail of the processes included in the original version. Consequently, their version may not be more useful than the original one in the development of support systems and training programs.

1.3.3 The RPD-OODA loop

Other work has addressed the issue of improving the underlying decision-making model and the related processes. Murphy & Glasgow [12] have proposed a modified OODA based on the Recognition Primed Decision-making model (RPD) developed by Klein [13]. It identifies five high-level processes: Monitor, Assess, Decide, Direct and Execute. The change in names of these processes has been necessary to reflect the generic processes included in Klein's model. Murphy & Glasgow go one step further and describe a number of activities, specific to a tactical operations centre, for each process. For instance, on top of the Decide process in itself, three activities are to be completed if time permits. These activities are: Solicit input from commander and staff, wargame and complete staff actions.

That particular adaptation of the OODA loop is the result of the objective of Murphy & Glasgow to link more closely the OODA to military decision-making processes as they are defined for planning purposes, for instance. The choice of the RPD model to adapt the classical OODA loop has previously been suggested by Breton & Rousseau [14]. Because of its naturalistic properties, they claim that the RPD model is the most appropriate model to represent the decision-making process in C2 environments. That effort would facilitate the translation of the OODA processes into tactics and procedures leading to an efficient OODA loop.

1.3.4 The execution decision cycle

Leedom [15] describes the Execution Decision Cycle (EDC) that is considered a more adequate model than the OODA loop for the design of support/automation tools. The EDC model is much more complex than the OODA loop. It expands the OODA loop on two basic aspects. First, it includes feedback/feedforward loops as well as explicit control nodes directing the flow of process with regards to parameters like time available, clearness of situation, scope of adjustment of selected COA and feasibility. Second, it adds a number of processes related to the testing of selected COA. The interesting feature of the EDC is that it is different from a classical process model typical of software design. In fact, it accommodates human decision-making processes within a form of flow model. The EDC model shares an objective with Murphy & Glasgow in making an effort to adjust a generic human decision-making model, Klein's RPD model [13], to current military procedures. Unfortunately, while Murphy & Glasgow [12] remain within the OODA loop architecture, the EDC does not.

1.3.5 The CECA model

Bryant [9] proposes the CECA model (Critique-Explore-Compare-Adapt) as an alternative to the OODA loop. Actually, the CECA model is not a modification of the OODA loop. It aims at replacing the OODA as a model of C2 decision-making. Figure 4 shows the CECA model. When compared with the usual perception-action loop models of which the OODA is typical, it appears readily that the CECA model does not include an ACT process. The CECA model focuses instead on the Observe, Orient and Decide processes of the OODA. Furthermore, while all perception-action loop models can be seen as a form of control system (i.e. acting on the environment to adjust current state with a desired state), the control process of CECA involves a situation model and a conceptual model as defined from a plan. So, any significant discrepancies between these two models require the adaptation of the plan. Then, it is the plan per se that is adapted and not the external world.

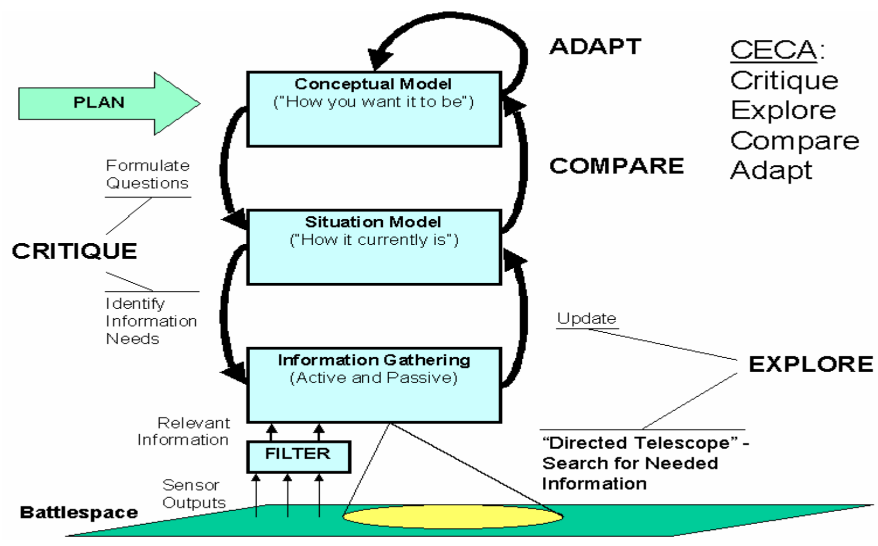

Figure 4: The CECA model [9]

The CECA model is based on two premises. First, a military operation, at all levels, must begin with a plan. Second, the plan must be goal-directed and it should describe the states of the battlespace one wants to achieve across a specified period of time. According to Bryant, the plan becomes the basis of the conceptual model used in the decision-making loop.

The CECA model is a very interesting that is more focused on the action planning. The objective of the CECA model is to provide an alternative for representing C2 decision cycle. However, it does not keep explicit the four high-levels of the OODA that are generally accepted in the military community.

1.3.6 The OODA loop as a functional model

In the tradition of Lawson's [16] model, the OODA loop can be viewed as a function model. There is currently an important body of work on functional modeling in the computer science domain. Within the defence community, the Department of Defence Architecture Framework (DoDAF) is more and more adopted for the modeling of large systems functions and processes. DoDAF is a framework for the development of systems or enterprises architectures (EA). All major U.S. Government Department of Defense (DoD) weapons and information technology system procurements are required to develop an EA and document that architecture using the set of views prescribed in the DoDAF.

While DoDAF as such is not useful for modeling small-scale systems like the OODA loop, it is of interest to take a look at its constituents like the Integration Definition for Function Modelling Ø (IDEFØ). IDEFØ is a method designed to model the decisions, actions, and activities of an organization or system. IDEFØ was derived from a well-established graphical language, the Structured Analysis and Design Technique (SADT). The United States Air Force commissioned the developers of SADT to develop a function modeling method for analyzing and communicating the functional perspective of a system.

It is not our purpose to try to model the OODA loop with these modeling methods since it has been done recently by Grant [17]. He applied the SADT/IDEFØ graphic modeling notation to the OODA. SADT is an important part of the IDEFØ method. Figure 5, presents the model proposed by Grant.

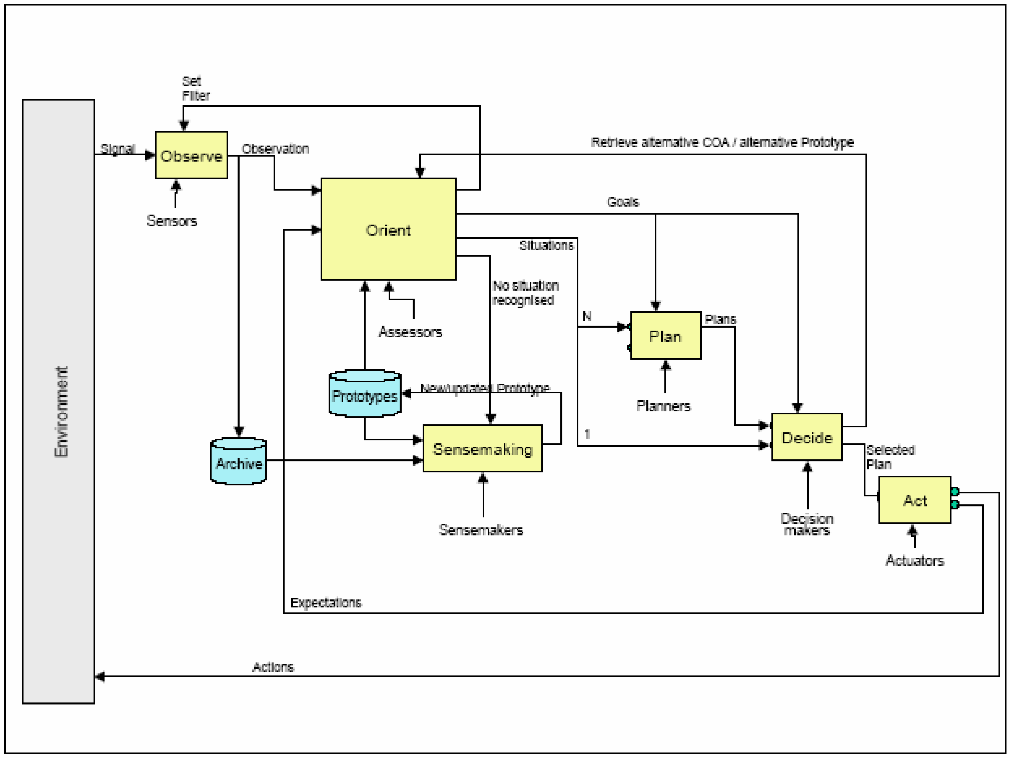

Figure 5: A functional model of the OODA loop based on SADT/IDEFØ method [17]

An examination of the model brings up a number of observations:

- The basic four functions of the OODA are kept in the model but two more functions are added: Plan and Sensemaking. These two functions fill in the need for planning and learning in the OODA. The Sensemaking process is a sub-process of the Orient function. It provides means to generate prototypes/patterns from an unknown situation and store them into a prototype database that supports a pattern recognition process in the Orient function. Given its functional status, the Plan function could also be considered as a sub-process of the Orient function. The CECA model did not keep the basic OODA processes but expanded the Observe-Orient-Decide processes with explicit reference to a planning process somewhat like Grant is suggesting.
- There are numerous feedback loops between the different components of the model. These feedback loops connect the four basic OODA components. The Plan and Sensemaking processes do not have control properties as should be displayed by feedback connections. The need to incorporate feedback links in the original OODA loop has long been recognized and these links are now part of the current view of the OODA loop.
- Finally, the connections between the basic functions of the OODA loop are not in a strict sequential manner.

Grant's model is a valuable improvement to the OODA loop. It uses a known functional modeling tool and improves the set of processes. However, the IDEFØ is also incomplete since process entry conditions can only be stated in terms of input availability. Similarly, a process ends when the output products have been completed. Also, IDEFØ does not contain a method for stating attributes of processes and products. We consider that while of interest, that approach keeps a black-box position towards the cognitive processes included in the loop. It appears of limited value as a means to model a dynamic control system.

1.3.7 The OODA loop in NCW and EBO

In the dual context of Network Centric Warfare (NCW) and of Effect Based Operations (EBO), Smith [18] discussed the value of the OODA loop. While acknowledging the usefulness of the OODA loop to represent a decision cycle applied to operational level interactions, he argues that it is limited by the particular operations (pilot-to-pilot air combat) that it was developed to represent. He claims that the OODA lacks the complexity one is faced with in larger operations involving multiple units and longer time scales, for instance. Smith presents an expanded version of the OODA loop (see Figure 6) that covers a general set of military operations from data understanding to action implementation. That coverage corresponds to the domain of the OODA loop.

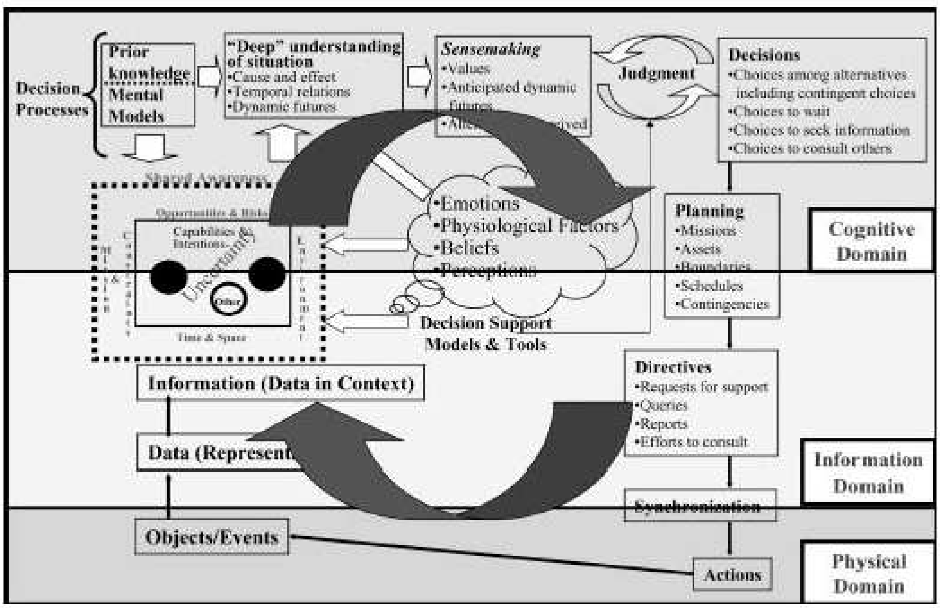

Figure 6: The OODA loop adapted to NCW and EBO [18]

Smith's version of the OODA adopts a partitioning of the OODA cycle in three domains: physical, information and, cognitive, that is more and more accepted in modeling of C2. It also includes in detail the cognitive components that are required for handling complex military operations in the context of NCW. A two-part decision-making process is described with control loops enabling Understanding/Knowledge/Information on one hand, and Sensemaking/Decision on the other. The representation of the decision-making process in Smith's OODA is very complex and includes a very large number of concepts with more or less details.

Alberts, Garstka, Hayes, & Signori [19] have presented the seminal concepts of NCW in their *Understanding Information Age Warfare*. They refer to the OODA loop as a traditional C2 model that is sequential and does not correspond to the current understanding of expert decision-making. Furthermore, they consider the OODA loop as being limited to a representation of direct tactical operations. They also suggest the same three domains; physical, informational and cognitive to be considered to address the new challenges brought up by the information technologies as the basis for conducting military operations. The physical domain is the environment in which operations take place with the physical platforms and communication networks. The information domain is where information is created, manipulated and shared. With the exception of direct sensory observation, the information an operator has about the world results from interaction with the information domain. The cognitive domain exists within the information processes of an individual with knowledge and values and other intangible properties of decision-making processes. It is the domain of awareness, understanding and sensemaking. The elements of the C2 decision making-cycle span across these three domains. Recently, Alberts & Hayes [20] have added the social domain to the first three.

1.3.8 The C4ISR model

Alberts et al. [19] argued that the OODA loop oversimplifies command and control. They proposed conceptualizing C4ISR process (Command, Control, Communication, Computer, Intelligence, Surveillance, Reconnaissance) as an adaptive control system seeking to influence various aspects of an operating environment. The C4ISR process is seen as a set of eight interacting elements: 1) Battlespace Monitoring; 2) Awareness; 3) Understanding; 4) Sensemaking; 5) Command Intent; 6) Battlespace Management; 7) Synchronization; and 8) Information Systems. This framework can be reduced to three primary functions involved in a C2 task: Operational space monitoring, sensemaking and operational space management. Monitoring and management span across the cognitive, information and physical domains, while Sensemaking relates entirely to the cognitive domain. Sensemaking can be broken down into elements that relate to either monitoring (such as awareness and understanding), or management (development and articulation of command intent).

The information systems play a central role in Alberts et al. view. They enable a bridge from Battlespace monitoring to Battlespace management that can bypass Sensemaking. Actually, one could claim that Sensemaking and Information components have to be harmonized in order for that C2 system to produce its real benefits. We would like to claim that although Alberts & al. view is more detailed than the original OODA loop, it is still a high level process model with three basic functions: Monitoring, Sensemaking and Management. If we accept such a proposition, it becomes rather straightforward to map the OODA loop process to the functional model of Alberts & al. [19]. Figure 7 shows the Alberts et al view of C2 decision-making in background with the identification of the related OODA process in superposition. We do not intend to go into a detailed description of that mapping. The main point is simply to show that there is a nice compatibility between Alberts & al conceptual model and the OODA loop.

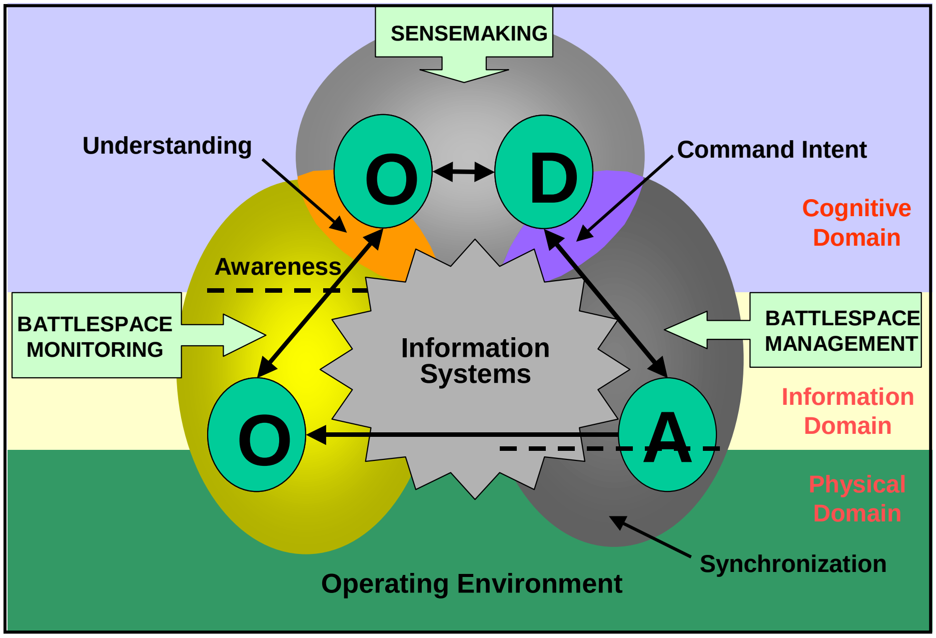

Figure 7: The mapping between the C2 decision-making model (Alberts et al) and the OODA loop processes

1.4 Comparison of OODA loop alternatives

Some attempts have been made to develop extended versions of the OODA loop. Some like the CECA model [9], the EDC model [15], Smith's adaptation for NCW and EBO [18], and the C4ISR [19] are completely discarding the original four high-level concepts in the OODA loop. Others, strongly influenced by the original model, offer more or less important modifications while trying to keep explicit the four OODA processes (Extended OODA loop [10], Iterative OODA loop [11]; RPD-OODA model [12]; Functional model [17].

Next Table presents an analysis of these different alternatives based on their level of similarity with the original version and the level of granularity of concepts (level of detail). Staying close (level similarity) to the original representation of the OODA loop could be an important for the acceptance of the model in military community. Appropriate level of details for concepts is essential to influence design of systems and development of training programs.

Table 1: Analysis of OODA loop alternatives

Model	Similarity	Granularity level of concepts
Extended OODA loop [10]	**Medium**: Feedback loops change considerably the model representation	**Medium**: Orient process more detailed than the others
Iterative OODA loop [11]	**High:** Only a control module added to the original version	**Very Low:** Details only provided for the control module
RPD-OODA loop [12]	**Low:** Process labels are changed in respect to the RPD model	**High :** Provide more cognitive details about the concepts included in C2 decision cycle
EDC model [15]	**Very Low:** EDC propose a completely different architecture	**High :** Provide more cognitive details on control loops, COA selection, etc.
CECA model [9]	**Very Low :** CECA propose a completely different architecture to replace the OODA loop	**Medium :** Provides details on planning, lacks a basic feature of perception-action loops
Functional Model [17]	**Low:** The addition of new processes and loops change drastically the model architecture	**Medium:** Details are still missing on the cognitive processes included in the model
NCW & EBO [18]	**Very Low:** It presents a completely new architecture	**High:** It provides considerable details with three domains (Physical, Information, Cognitive)
C4ISR [19]	**Very Low:** It presents a completely new architecture	**Medium:** It introduces three distinct concepts: Battlespace monitoring, sensemaking and battlespace management

Table 1 illustrates that the increase in cognitive granularity of concepts that is required for the design of appropriate support systems and the development of training programs often come at the cost of increasing significantly the complexity of the model representation. In these models, only the extended OODA loop and the iterative OODA loop present a representation close to the original OODA model. However, they do not offer much further cognitive details than the original version. The extended OODA loop only increase the level of details of the Orient process. On the other hand, EDC, CECA, NCW & EBO and C4ISR models all provide sufficient level of details on specific aspects of C2 decision-making. However, they propose completely new representations.

The simplicity of the OODA loop representation is frequently lost in more complex OODA alternatives. There is a need to bridge the gap between simplistic models favoured for communication purposes between communities and complex models that provide sufficient details for support systems and training programs design. One solution is to model C2 decision-making activities from a principles-based approach. Such modelling approach should allow increasing the level of details of the original OODA loop while keeping explicit its four high-level phases. Our principles-based approach uses the concept of modules. The next sections present the theoretical background that has influenced the development of our modular approach.

2 The M-OODA model

Most of the time, descriptive models are not easily transformed into formal prescriptive terms. They will provide rather general predictions. By comparison, prescriptive models are theory driven. They are characterized by the formal representation of processes leading to some computational modeling of C2 decision-making. In its original form, the OODA loop can be considered as a weak descriptive model. However, it is our contention that by adopting a principled modeling approach to C2 decision-making modeling, a more detailed OODA loop model can be derived from the original one. It can still provide a form of representation more consonant with formalization, mainly for the purpose of developing support tools for the C2 process and more particularly for the decision-making process.

2.1 The roots of the modelling approach

2.1.1 First principle: the notion of module

Lawson [16] presented a seminal paper in which the principles for modeling are introduced. Lawson treats C2 as a process in which different components have different roles while operating as parts of a larger system. Figure 8 represents Lawson's model.

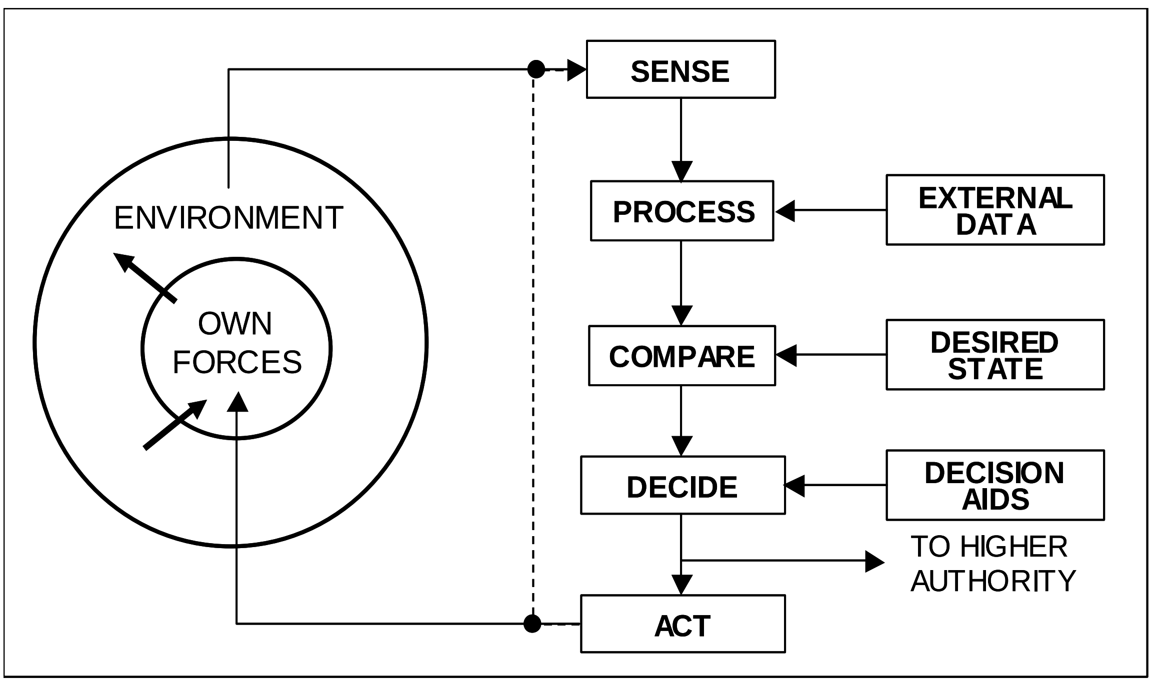

Figure 8: Process model of Command and Control proposed by Lawson [16]

It is worth presenting a number of features of that model, since these features have inspired families of models. First, Lawson's model presents a set of five processes that cover the essential functionalities for C2: ability to perceive the state of the environment (SENSE and PROCESS), compare that state with a specified desired state (COMPARE), and if required, take action into the environment to correct the current state (DECIDE, ACT). Second, the environment is partitioned in two components, own forces and general environment including adversary forces. Thus, the C2 model represents actions being taken on own forces and a monitoring of the effects of that action in the environment. The concept of comparing current state of the environment to a desired state and to perform error or discrepancy correction actions is typical of a basic cybernetic model. Such conception is somehow similar to the one proposed in the Perceptual Control Theory (PCT). In PCT, the presence of feedback is essential for the control of goal-directed human activity. Actions are set to reduce the discrepancy between the human desired state or goal and the perception of the actual situation.

Allard [21] quotes Lawson [22] on a very critical property of such components:

> "The various parts of a C3I (Command, Control, Communication and Information) system must be pretty much self-contained. It must perform definable and separable functions so that one can change one *module* without affecting the others".

The notion of module proposed in Lawson's model is very interesting. The modular architecture proposed by Lawson is thus very adaptable. In a way, Lawson's model is in line with the more recent concept of EBO [18].

2.1.2 Second principle: bi-directional communication link

McCorry & Morse [23] presented an update of the DARPA Joint Force Air Component Commander (JFACC) program. The program aims at providing C2 with a prosthesis type of technology for decision-making support. For doing so they describe an approach based on a Multi Hierarchical Decomposition of a control node that is formed by a set of five processes that are almost identical to the OODA loop. The processes in the control node are interrelated with bi-directional communication links.

From their modeling effort, a number of statements are highly relevant for deriving principles for the design of the M-OODA model. In the JFACC control model, each process of the loop is defined as a level. It then follows that each level requires different models with different levels of aggregation of time and objects. In the model, there is a systematic flow of state observation data that flows upward and downward from a level to another. That requires systematic mappings between levels, since each level is modeled differently. Indeed, the transmission across levels has to take into account the properties of the target level. In fact, they claim that the upward transmission of information should be in terms of aggregated events and pictures. Similarly, the downward flow is a privileged channel for transmission of command information. Here again, an adequate mapping is essential for adapting the higher-level aggregation into low-level aggregation with higher temporal and spatial granularity, for instance. The M-OODA model adopts a similar point of view with systematic communication and control links between processes.

2.1.3 Third principle: the building block

The architecture of the M-OODA model is based on the concept of building block. That approach bears resemblance with the model proposed by Curts & Campbell [24] in the context of applying Object Oriented Data Bases (OODB) concepts to the OODA. Their model has a formal architecture in which functional building blocks can be assembled to form large-scale processes or databases. These basic blocks have three components: Processes, Attributes of processing and Functions. Then, it appears that applying the building block approach to the M-OODA is of interest since that approach has shown to be adapted to formal representation in the context of the design of software support tools. The M-OODA modules resemble the OODB blocks except on two points. First, given the commitment in the M-OODA to the control processes in C2, the third component of the M-OODA module is not a generic function but a more specific control function. Second, the modules are designed as simple control systems, which is not the case in the OODB model.

The modular approach

Previous sub-sections identify principles that are included in the modular approach from which the M-OODA is derived. Hence, the M-OODA model modifies the OODA loop based on these following principles:

- It adopts a modular architecture in which each process of the OODA loop is represented as a generic module structured around three components: Process, State and, Control;
- It incorporates explicit control elements within and across modules enabling a bi-directional data/information flow between modules. It also includes a feedback loop within each module. These explicit control and flow components are more in line with the current understanding of military C2;
- Modules are seen as building blocks.

A number of modules are structured in an OODA loop fashion and interconnected by feed-forward and feedback loops. These loops enable information flows and coordination means between modules. The M-OODA model is then a simple dynamic system enabling the control of the tasks/processes already identified as representing a commander's decision-making capability.

Modularity is a concept that has applications in the contexts computer science, particularly in programming. It is also used in the context of cognitive science in investigating the structure of mind. A module can be defined variously, but generally must be a component of a larger system, and operate within that system independently from the operations of the other components of the system.

The M-OODA proposes a basic architecture based on the concept of cognitive modularity with properties of domain-specificity of inputs and process encapsulation. Cognitive modules are characterized in particular by specific input conditions and by proprietary resources used to process inputs that meet these conditions [25. The inputs that happen to meet the input conditions of a given module constitute the proper domain of the module. The function of the module is to inform the system about items in its proper domain. It is with reference to such a proper domain that a module can be said to be domain-specific. It is important to distinguish domain-specificity from encapsulation. A device is domain-specific if its function is to process only inputs belonging to some specific empirical domain. An encapsulated device is one that uses a limited database to process its inputs. In the modelling approach of the M-OODA, the modules have these general properties of cognitive modules.

2.1.4 The M-OODA basic module

The basic module is the core component of the M-OODA model. The application of a modular approach to the OODA loop requires first to define the properties of a module in that context. Cognitive and computer approaches to the concept of module define a module as a process. That is very much in accordance with the classical OODA loop and the process modeling tradition of C2.

However, as we have seen before, the new concepts of warfare emerging from the pervasive use of information technologies, requires a distribution of control and, up to a point, command in C2. In the M-OODA model we propose to define a module as a set of two classes of functions: Process and Control:

- The process component transforms an input into a state according to its basic properties. The state is then represented as a component of the module, albeit of a different nature. It is not an active process.
- The control component determines within module iterations and transfer of information to other modules. The inclusion of a control component within all modules enables the distribution of control within a network of modules. That structure requires then means of communication between components within a module.

Figure 9 presents the structure of a basic module. As can be seen, a module has a set of 8 elements: the module name, three core components (process, state, and control), two feedback loops and input/output connections. Each element of the module is described in the following paragraphs.

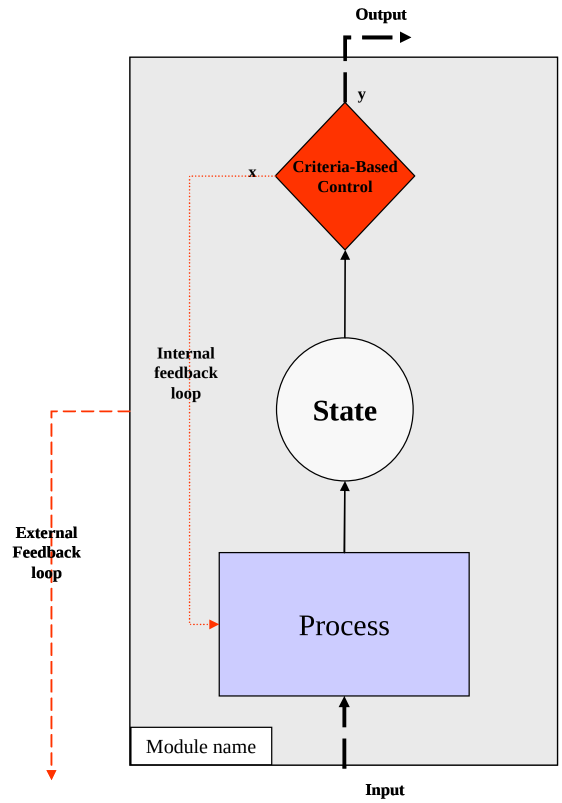

Figure 9: The structure of the basic module

Module Name: The module name corresponds to the specific process included in the module. A module name is composed of an operation and an object on which the operation is applied. Actually, the name of the module reflects the general goal of the module within the M-OODA model. For instance, in the Data Gathering (name-operation) module, the goal is to gather data from the environment. Thus, module name is more than a simple label; it is a high-level determinant of the nature of the process, resultant state and related control criteria within a module.

Input: In most cases, inputs are mainly outputs from other M-OODA modules. Information from the environment can also contribute to the Input of a given module. Depending on its goal and on the current situation, the relative importance of these two sources will vary. While we acknowledge that a module operates in a general environment where objects are present and actions are occurring independently of the specific task goal, we limit the input to the states represented in the M-OODA model.

Process: The process is the core active component of a module. It is a goal-directed action applied on an input. Its properties depend on the nature of the goal. A process will generate a state in the module. The process is given a generic name that is closely related to the action included in the module name. For instance, in the Situation Understanding module, processes such as understand, identify, organize, and form hypothesis can be used to represent the module goal-oriented activity. This goal is achieved by an agent that can be a human, an automaton or a combination of both. The Process is actually viewed as a generic component that can be subdivided into sub-processes. For instance, a process could be Select a course of action. It is obvious that such a label covers a number of sub-processes that would model that specific process.

State: The state is the result of the process activity. It is a structured representation with properties depending on the nature of the process from which it originates and of the input that was fed to the process. The granularity of the aggregation in time and space is likely to vary with the specific processes. The general properties of the state are also constrained by the module goal.

Control: The criteria-based control component is a flow control function gating the delivery of the output to other modules and enabling iterations of the process within the module. Control can interrupt, iterate the process or exercise no gating function depending on the mode of operation required. It can accept a given level of state quality (uncertainty level) depending on task-goal criteria. Since they are goal related, the control criteria should be different from one module to another. According to Breton & Rousseau [14], different types of uncertainty are related to the different components of the OODA loop. Vagueness, beliefs, value and feasibility are types of uncertainty respectively associated with Observe, Orient, Decide and Act. On top of all possible criteria, time and quality can be the most important ones.

Output: The Output is the current status of the state resulting from the process that reaches an acceptable level of quality based on the criteria-based control component. The resulting output becomes the input for a subsequent module.

Internal feedback loop: The internal feedback loop (IFL) is an iteration request based on a set of criteria included in the control component. The iteration request can be based on the need for improved quality in state or for increased quantity of state content, focus on repeated processing of part of the input, or need for updating the content of state.

External feedback loop: The External Feedback Loops (EFL) are somehow similar to those included in models developed from the JFACC program [23]. They allow information flow, communication and coordination among the different modules (see the doted red arrows connecting the modules). We label target module, the module towards which the EFL is directed. The nature of the information transmitted from the EFL is based on the nature of the module state. There are two kinds of EFL: The Request loop (R-El) and the Transfer loop (T-El). The R-El is a loop originating in the need for an improved input (state not reaching standards) to a module in order to enable an adequate or maximal state. It is thus a request, initiated from the control component that is addressed to the modules that control the input to a given module. That request will then be adapted internally, within the target module, in terms of an internal control loop. The T-El is a passive transfer of the status of the current module to other modules or other non-task-goal related processes. This transfer is also initiated from the control component of the module. It produces a form of broadcast in the system. It takes the form of a feedback or of a feed-forward loop depending on the position of the target modules. The transmission of commander intent would flow downward through the T-EL. Table 2 gives a summary of the parameters defining each component of a module.

Table 2: Summary of the parameters included in the M-OODA basic module

Component	Parameters
Module name	[object, operation (i.e. Data Gathering)]
Input	[physical signal, OODA state, non-OODA input]
Process	[action verb (Sense, Gather, Understand, etc)]
State	[object, representation, goal-determined properties, process-specific properties]
Control	[time, quality (level of uncertainty, goal-related criteria]
Output	[current State]
Internal loop	[State quality criterion, state completeness criterion, update monitoring]
External loop	R-El: [time, information criterion, number] T-El: [State status, control status, command information].

A M-OODA module represents a task-goal directed activity supported by a set of components. It can be seen as the basic structural element of a goal-directed system. The module has components whose function is to produce the expected state following the appropriate process according to preset control criteria. Within a module, feedback loops make possible communication between components of a module. They support an iteration request based on a set of criteria included in the control component. On top of that, a module has components required for interaction with other modules and the general environment. With these loops, the flow of activities in the M-OODA model is dynamic and multi-directional.

2.1.5 The processes in the M-OODA

In all models defining the decision-making cycle, the processes included are often stated with interchangeable labels. However, they generally include these four generic phases: data acquisition, information understanding, decision, and decision implementation. In the M-OODA loop, these four generic phases are represented with Object-Verb structured labels. The verbs used represent the goal-oriented function of the module. The main objective with the use of such labelling is to keep intact the high-level representation characterizing the classical OODA loop (Observe-Orient-Decide-Act) and to highlight the goal-oriented processing as reflected by the Module names. That leads to changes in the labels associated with the OODA processes in accordance with the specifications of the Module Name in a module.

Table 3: Modifications to the processes labels of the OODA loop

Original OODA Loop Processes	**M-OODA Loop Processes (Object-Verb)**
Observe	Data-Gathering (DG)
Orient	Situation-Understanding (SU)
Decide	Action-Selection (AS)
Act	Action-Implementation (AI)

The M-OODA module names are presented in Table 3 in relation with the original processes of the OODA-loop.

The M-OODA model is developing from these following principles:

- The M-OODA loop is developed by representing each OODA process with a basic module as described above.
- The M-OODA shares with the classical OODA the sequential operation of the modules.

In such a model, the output of a module is strictly linked to the input of a subsequent module. While the external feedback loops support dynamic and recursive processing, it is that Output/Input connection that enables the sequential operation of the M-OODA cycle.

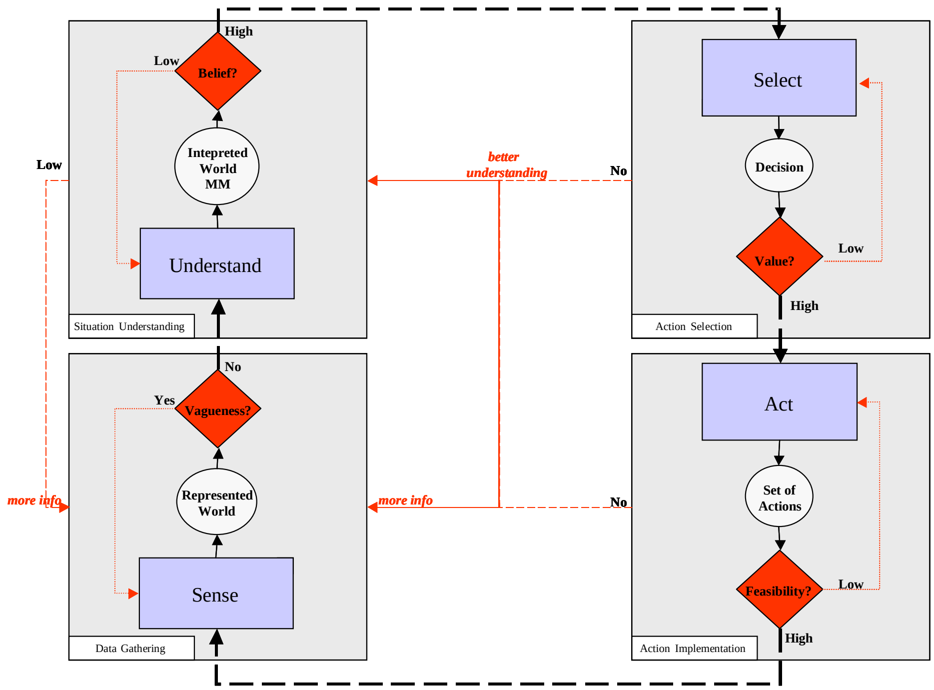

Figure 10: The M-OODA loop

The M-OODA architecture is presented in Figure 10. It is composed of four modules, each one associated with the processes of the OODA. Each module is specified by the three basic components (Process, State and Control). The external feedback loop (EFL) and the internal feedback loop (IFL) are links that maintain the same properties no matter the specific module. Furthermore, as defined in the basic module, Input/Output connections are redundant representations of the state component when described strictly within the M-OODA. In each module, the process (P), state (S) and control (C) are given a generic label in order to simplify the representation of the M-OODA. As stated before, the P can be seen as, in fact, an organized network of sub-processes that can be active depending on the specific task-goals and current constraints in the environment. We assume, for simplicity, that EFL can link a given module with any previous one, as represented with the red dotted arrows in Figure 10.

2.2 Walkthrough the M-OODA

In the DG module of Figure 10, data are sensed from the environment. From this process, a given representation of the world is built (state). Control criteria-based component evaluates the quality of this state based on its level of vagueness, completeness, fuzziness, etc. (certainty). Such control processing is stopped when the level of certainty reaches a satisfying level or there is no time left in the situation for further iterations. Iterations are made from the IFL. At this time, the resulting state with its level of certainty is fed into next module as inputs.

In the SU phase, the resulting state of the preceding module is fed into an understanding process in order to build an interpreted world. Then, the state goes from a world representation to a world interpretation. Such interpretation is evaluated based on its level of familiarity, plausibility, etc. Iterations are possible, from the IFL, until an acceptable level is reached or the time is elapsed in the situation. If further data are requested for better understanding, a request can be sent through the EFL to the DG module. This can be done if there is enough time available in the situation.

In the next module, the AS module, the resulting state of the SU is considered as input for the select process. Its role is to define a potential decision from the situation understanding or the interpreted world (SU state). Such decision is then evaluated by the control component based on its level of risk, completeness of options, cost assessment, etc. Iterations are possible, from the IFL, until an acceptable level is reached or the time is elapsed in the situation. Also, request can 0be sent from the EFL to the DG module if more data are needed, or to the SU module for further reasoning, validating processing.

In the last M-OODA module, actions are implemented. Then, the resulting state of the AS module, the decision is transformed into a set of actions (state of the AI module). Here again, this state is evaluated by the control criteria-based component based on the set of actions feasibility level, etc. Iterations are possible, from the IFL, until an acceptable level is reached or the time is elapsed in the situation. Also, request can be sent from the EFL to the DG module if more data are needed, to the SU module for further reasoning, validating processing or the AS module for further options.

2.2.1 Description of the core component of the module

A detailed description of the core components of each module is given in Table 3. We do not claim that the table provides an exhaustive and necessary description of the components specific to each module. Actually, the extensive list of processes presented in Mayk & Rubin [26] could expand the number of processes already listed in Table 4. However, it provides a very good approximation of these components. We have made an attempt at describing the specificity of each core component within each module. We have also made an effort to keep these specific components at the level of a model. Furthermore, there is no assumption as to the nature of the agent associated with particular processes within a given module. In fact, an agent, human or automaton, with a specific set of skills and resources owns a specific module.

Table 4: Specifications of the core components of the M-OODA

Module	Process	State	Control
DG	Sense, encode, register, data translation, scan, fuse, detect, monitor	World representation, object/background, multimodal-integration	Vagueness, completeness, fuzziness, time available, quality of picture
SU	Understand, identify, categorize, classify, organize, schematize, recognize, form hypothesis, simulate	Mental model, schema, episode, familiarity estimation,	Belief in interpretation, familiarity of schema, uncertainty on meaning
AS	Select, choose, identify options, apply rules, consult	Decision, list of actions (COA), risk evaluation, expected gain, rules	Risk assessment, completeness of options, cost assessment, gain estimation, familiarity of situation
AI	Act, planning, resource management, constraints, milestone definition	Set of actions, schedule, milestones, plan, mission, orders	Feasibility, acceptability, resource availability

3 Discussion

In previous sections, we have presented a modular approach to model the decision cycle in C2 environment. From this modular approach, a modular version of the OODA loop, the M-OODA loop has been proposed. In this section, we discuss these following points:

- The nature of the processing within the M-OODA model (automatic versus controlled).
- The issue of control in the M-OODA loop.
- The entry point in the model and the interactivity among modules.
- The nature of the information transfer within the M-OODA (throughput).
- The communication between the modules.

3.1 Controlled versus automatic processing in the M-OODA

Schneider and Shiffrin [27] make a distinction between automated and controlled processing. Controlled processing requires time and cognitive and attentional resources. Automatic processing does require minimal attentional resources. At the automatic level, the task is performed unconsciously. In the context of the M-OODA model, outputs with high level of familiarity can initiate automatic process in subsequent module. For instance, when a familiar output, produced by the DG module is fed into the SU one, it triggers an automatic recognition (situation well understood) which also triggers the activation of well-known and familiar set of actions from the AS module. This automatic answer is fed into the Action Implementation (AI) module. In this very familiar situation, attentional resources are only required to execute the DG and AI modules. SU and AS can be executed on an automatic, non-controlled mode.

3.2 The issue of control in the M-OODA

In the context of C2, we approach military control as defined by Pigeau & McCann [33]. The basic feature of military control is that it can be characterized as a form of cybernetic control. That implies a feedback mechanism by which some input, reflecting the outcome of previous action in the environment, is compared to some goal or expected state. Actions are then taken to reduce the difference between the current state and the expected or goal state.

However, military control, according to Pigeau & Mc Cann [33] is more than a mere closed-loop feedback control system. It implies all the structures and processes (including the cybernetic control processes) put in place to facilitate the accomplishment of a mission. The notions of processes and structures are central to military control. So, they define control processes as a set of regulated procedures that allow control structures to perform required work. Given that definition of military control, the M-OODA module is seen as a control structure with embedded processes that directly support command. Command is defined as the expression of human will necessary to accomplish a mission. As we have states before, control should appear as a distributed property of the C2 system, and consequently, of the OODA loop while command is more a property of decision-making and intent. The structure of the M-OODA is viewed as a loosely coupled system with modules having the local freedom to operate within the context of the overall system and constraints imposed by the high-level command.

3.3 The entry point of the M-OODA

In the classical model of the OODA loop, the implicit entry point is the Observe phase. This single entry point conception is one of the critics of the OODA loop. In the M-OODA model, no specific entry point is suggested. All the four phases can initiate the decision-making cycle. In fact, as suggested in Figure 11, all modules can play the role of an entry point depending on the situation.

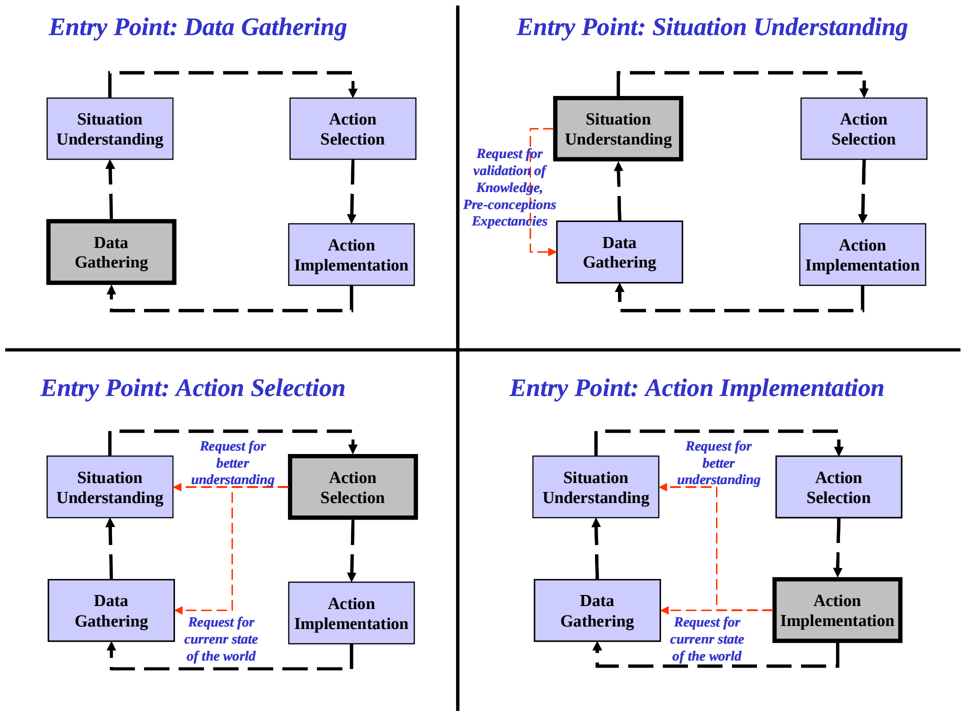

Figure 11: The M-OODA loop entry points

The left-upper part of the Figure represent the most usual and classical vision. The decision-making cycle is initiated from the acquisition of specific data from the environment. In the right-upper part of the figure, the decision cycle is triggered from a need to validate a specific knowledge or to validate pre-conception, feeling or intuition. Such need is transmitted back to the DG module from the External Feedback Loop (EFL). It is more representative of a top-down approach. In the left-lower part of the figure, the decision cycle is initiated from the need to react to a sudden event that happens in the situation. In this reactive mode, the decision maker needs to track down the event occurring. Here again, requests are sent through the EFL. In the right-lower part of the figure, the decision cycle is initiated from a request sent through the EFL for immediate action. The difference between this situation and the one represented in the left-lower may simply be the time scale. The need for immediate action may be more representative of extreme urgency. The red dotted arrows in Figure 11 represent the implication of the EFL.

3.4 The throughput of a module

When applied at the human agent level, it becomes possible to consider the power of a module in terms of speed of transfer of information, or throughput. The basic property of a level is that it operates within a specific temporal band. Newell [28, 29] proposes four levels for an intelligent system: biological, cognitive, rational, and social. While their labels may change, these levels are similar to those proposed by Alberts and Hayes [20]. The biological level is sub-symbolic, the cognitive level is symbolic, the rational level is task based and the social level is about culture and organizations. It suffices to say that for Newell the biological level is the fastest and the time band slows down moving from cognitive to rational and to social levels. It follows that the same structure of time bands could apply to the C2 domains corresponding to a given level.

It is of interest to consider that the time band could provide an estimate of a single cycle time within a module when that module is classified as operating within a given domain. Given that estimate of cycle time, it also becomes the estimate of the minimal time required for updates of the output provided by the module. In addition, the update rate will also depend on the value of the parameters set in the control element with regards to the criteria for output transfer.

The interest of such considerations about time scale of cycle times within different classes of module is that it stresses the asynchrony of these modules cooperating within a given task architecture. One instance of problem that can arise from that asynchrony concerns the interest in providing the fastest update rate to a slower module. Consequently, subsequent slower module could work on given inputs that are drastically different (updated many times by faster cycle time module) than the one prevalent at the onset of the module process. Although change in world state will always be the case in a dynamic world, important discontinuities in successive context states coming from the temporal properties of systems interfacing the world with a decision maker can lead to erroneous conclusions.

3.5 The M-OODA: Between module communication

In a modular C2 model, between-module communication is determined in large part by the domain specific input property of formal modules. In a network of modules, albeit simple, applying that principle leads to a strict architecture where a functionality of a module can be seen as transforming an input into an output that becomes part of the domain specific input of another module. Now, depending on the scope of the domain of a given module, that output has to be more or less specific or restricted. Actually, if a given module has an extremely broad domain (less specific), it will accept inputs from a large number of modules, leading to a form of data explosion. There has to be some trade-off between very narrow specificity of a particular module and all-purpose input of another one. Specificity brings constraints in a modular net by restricting possible between-module links. Specificity reduces contextual information about the state of a network that comes with inputs from a variety of information sources.

One possible solution to that trade-off is to include two types of between-module communication.

- The first one is a classical input-output link where modules are interconnected on the basis of limited-scope domain specificity. As stated earlier, that form of connection is strongly related to the architecture of a modular system.

- The second one is a form of broadcast that sends information across a modular network.

Broadcasting informs other modules about the state of the emitting module and provides context for interpretation of the specific input. A major drawback of broadcasting comes from the multiplicity of diverse inputs to a given module, increasing the complexity of the interpretation of these diverse elements of information. In the context of Network Enabled Operations (NEOPs) and increased power of information system, it has become possible to organize broadcasting into what is called a Common Operating Picture (COP). The COP simplifies contextual interpretation of a given situation. It reduces the complexity coming from a large number of unstructured information inputs by creating patterns and structured representations of the state of the situation and of the modular system. However, limiting the input to a module to broadcasting has a serious side-effect. It requires complex processing from a module that has to isolate, in an appropriate way, the domain-specific information that is specific to its processes.

Thus, the M-OODA incorporates both types of between-module communication:

1. Specific output-input connections based on domain specificity;

2. Large band broadcasting that provides contextual information.

4 Conclusion

We have presented a descriptive model of decision-making in C2, the M-OODA, based on the classical OODA loop. It provides a means to model decision-making at the required level of complexity while maintaining the coherence of the model. Throughout this document, it is suggested that the modular approach, based on building blocks, has been a useful tool to describe the decision-making process in C2.

Furthermore, the M-OODA model support NCW/NEOPS concepts when its modules are defined as capabilities where the processing specificity of a module is seen as an asset in terms of goal achievement and by providing explicit means of information flow within and across modules. It accommodates adaptability and flexibility inherent to dynamic and networked systems by including a distributed control function and explicit feedback and feed-forward loops. The modular structure provides a way to represent the ability to reconfigure forces and thus providing force agility.

The M-OODA loop is a simple adaptive network of modules. The control nodes with the feedback/feedforward loops make the M-OODA loop sensitive to time pressure and requests from higher-level processes for specific information. The control module also serves the function of mapping the demands from other modules to the reality of a given module. This is an important function that recognizes the need for such a mapping. Then, the M-OODA loop keeps its valued high-level representation while accommodating dynamic adjustments compatible with command and control requirements.

4.1 The M-OODA framework

In its current status, the M-OODA is a framework that could be adjusted to specific requirements. Each core component could be modeled and further complexified for the purpose of modeling a specific aspect of C2 decision-making. The M-OODA can be seen as a layered system in which different parts can be exploded for more details. That layered aspect is an emerging property of the M-OODA and makes it compatible with complex decision-making models or data fusion models, for instance.

The M-OODA framework (see Figure 12) led to the development of other OODA model addressing different aspects of C2. For instance, Breton and Rousseau [30, 31] presented a version of the M-OODA loop that addressed the team dimension (T-OODA loop). Breton and Rousseau [32], in a cognitive version of the M-OODA loop, the C-OODA loop, increased the level of cognitive granularity of the M-OODA loop in order to better influence the design of decision aids adapted to C2 environments. Altogether, the M-OODA, C-OODA and T-OODA offer a framework to illustrate the different aspects of C^2.

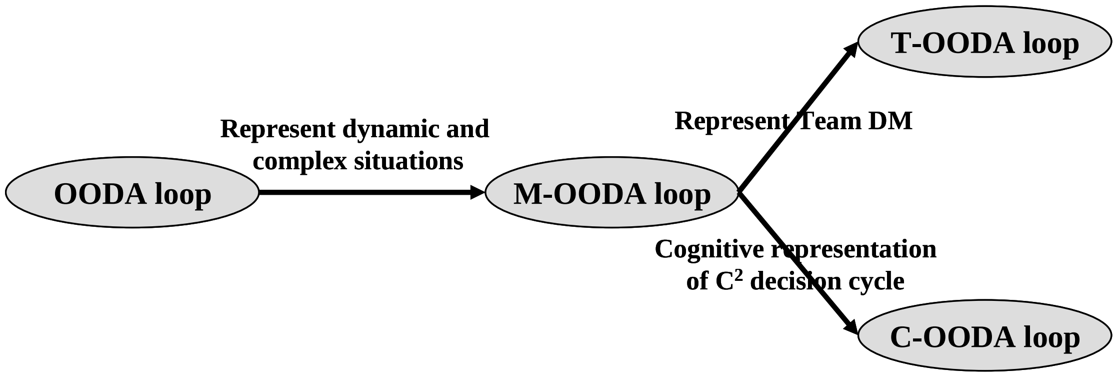

Figure 12: The M-OODA framework and related C2 models..

The fact that all these models that address different aspects of C^2 take their roots into the classical version of the OODA loop can be a positive factor in the acceptance of these models by the military community. The whole set of these different OODA loops provides a general framework to 1) represent dynamic and complex situations (M-OODA), 2) represent team decision-making (T-OODA) and 3) provide a cognitive representation of the C^2 decision cycle. By taking their roots in the OODA loop and being based on the same architecture, these models are compatible altogether. They benefit from the advantages related to the OODA loop while addressing specific OODA loop limitations.

References

[1] Boyd, John, R. (1987). From the unpublished collection of briefing slides entitled "*A Discourse on Winning and Losing.*" Maxwell AFB, AL: Air University Library, Document no. M-U 43947.

[2] Brehmer, B. (1992). Dynamic decision-making: Human control of complex systems. Acta psychologica, 81, 211-241.

[3] Rasmussen, J. Pejtersen, A. M. and Goodstein, L. P. (1994). *Cognitive Systems Engineering*. New York: Wiley.

[4] Jagacinski, R. J. and Flach, J. M. (2003). *Control Theory for Humans.* Mayhaw, NJ: Lawrence Erlbaum Associates.

[5] U.S. Army Field Manual 6.0 (2003). *Mission Command: Command and Control of Army Forces.* Headquarters, Department of the Army, Washington, DC.

[6] US Air Force Doctrine document 2-8. (1999). *Command and Control*.

[7] US Navy Doctrine Document 6. (1995). *Naval Command and Control*. Department of the Navy.

[8] Plehn, M. (2000). *Control warfare: Inside the OODA loop.* Unpublished Master's Thesis, Air University, School of Advanced Airpower Studies, Maxwell AFB, AL.

[9] Bryant, D., (2003). Critique, Explore, Compare, and Adapt (CECA): A new model for command decision-making. Defence R&D Canada – Toronto, TR 2003-105, July 2003, 49 pages.

[10] Fadok, D.S., Boyd, J., and Warden, J. (1995). *Air Power's Quest for Strategic Paralysis*. Maxwell Air Force Base AL: Air University Press, (AD–A291621).

[11] Breton, R., and Bossé. E. (2002). *The cognitive costs and benefits of automation*. Paper presented at NATO RTO-HFM Symposium: The role of humans in intelligent and automated systems, Warsaw, Poland, 7-9 October 2002.

[12] Murphy, and Glasgow (2000). *Insights into optimum TOC environments*. Proceedings: 2000 Command & Control Research and Technology Symposium (CCRTS), U.S. Navy Post-graduate School, Monterey, CA, June 24-28.

[13] Klein, G. A. (1993). *A recognition-primed decision (RPD) model of rapid decision-making.* In G. Klein, J. Orasanu, R. Calderwood, & C.E. Zsambok (Eds), Decision making in action: Models, and methods (pp. 138-147). Norwood, NJ: Ablex.

[14] Breton, R., & Rousseau, R. (2002). *Decision making in C2: From a person-task perspective.* Defence Research Establishment Valcartier, TM 2001-219, September 2002, 49 pages.

[15] Leedom, D. K. (2001). *Modeling organizational decision making in military command and control.* Proceedings of the Modeling of C2 decision processes workshop, Evidence Based Research Inc.

[16] Lawson, J. S., (1981). *Command and Control as a process*. IEEE Control Systems Magazine, March, pp. 5–12.

[17] Grant, T. (2005). ACM International Conference Proceeding Series; Vol. 150 archive Proceedings of the 2005 annual research conference of the South African institute of computer scientists and information technologists on IT research in developing countries table of contents White River, South Africa, Pages: 159 - 170

[18] Smith, E. A. (2002). *Effects Based Operations*. Washington DC: DoD CCRP Publications.

[19] Alberts, D. S., Garstka, J. J., Hayes, R. E., and Signori, D. A. (2001). *Understanding Information Age Warfare.* Washington, DC: CCRP Publications.

[20] Alberts, D.S. and Hayes, R.E. (2003). *Power to the edge: Command and Control in the information age*. DoD Command and Control Research Program.

[21] Allard, C. K. (1996). *Command, Control, and the Common Defense*. Revised Edition. Washington D.C.: National Defense University Press.

[22] Lawson, J. S. (1979). *Naval tactical C3 architecture 1985 – 1995*. Signal, 33:10, 71-72.

[23] McCorry, D. C. and Morse, S. H. (2000). *Bringing control theory to C2: An update on the DARPA JFACC program.* Proceedings: 2000 Command & Control Research and Technology Symposium (CCRTS), U.S. Navy Post-graduate School, Monterey, CA, June 24-28.

[24] Curts, R. J., and Campbell, D. E. (2001). Avoiding information overload through the understanding of OODA loops, a cognitive hierarchy and object-oriented analysis and design. Proceedings of the 6th International Command & Control Research and Technology Symposium (ICCRTS), U. S. Naval Academy, Annapolis, MD, June 19-21.

[25] Sperber, D. (2005). *Modularity and relevance: How can a massively modular mind be flexible and context-sensitive?* In The Innate Mind: Strucuture and Content, P. Carruthers, S. Laurence and S. Stich (Editors), Oxford, Oxford University

[26] Mayk, I., and Rubin, I. (1988). *Paradigms for understanding C3, Anyone?* In S. E. Johnson and A. H. Levis (Eds), *Science of Command and Control: Coping with uncertainty,* (p. 48-62), London, UK: AFCEA International Press.

[27] Schneider, W., and Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. Psychological Review, 84, 1-66.

[28] Newell, A. (1990). *Unified Theories of Cognition*. Cambridge, Massachusetts: Harvard University Press.

[29] Newell, A. (1992). *Precis of Unified Theories of Cognition*. Behavioral and Brain Sciences,15(3), 425-492.

[30] Breton, R. & Rousseau, R. (2006). *Decision-making from a team perspective*. Defence R&D Canada – Valcartier, DRDC Valcartier TR 2003-368, 59 pages.

[31] Breton R., and Rousseau R (2006). *The Analysis of Team Decision Making Architectures*. In M. J. Cook J, Noyes, & Y Masakowski (Eds.) Human Factors of Decision Making in Complex Systems. Ashgate Publishing limited, England.

[32] Breton, R., & Rousseau, R (2005). *The C-OODA: A Cognitive Version of the OODA Loop to Represent C2 Activities.* Proceedings of the 10th International Command and Control Research and Technology Symposium, Washington DC., USA, 2005.

[33] Pigeau, R. & McCann, C. (2000). *Redefining Command and Control*. In C. McCann & R. Pigeau (Eds), The human in command: Exploring the modern military experience. NewYork, NY: Kluwer Academic/Plenum Publishers.

This page intentionally left blank.

List of acronyms

AI	Action Implementation
AFDD	Air Force Doctrine Document
AFM	Army Field Manual
AS	Action Selection
C	Control
C2	Command and Control
C3I	Command, Control, Communication, Information
C4ISR	Command, Control, Communication, Computer, Intelligence, Surveillance, Reconnaissance
CECA	Critique-Explore-Compare-Adapt
COP	Common Operating Picture
DG	Data Gathering
DoD	Departement of Defence
DoDAF	Departement of Defence Architecture Framework
DND	Department of National Defence
EA	Entreprise Architecture
EBO	Effect-Based Operations
EDC	Execution Decision Cycle
EFL	External Feedback Loop
IDEFØ	Integration Definition for Function Modelling
IFL	Internal Feedback Loop
JFACC	Joint Force Air Component Commander
M-OODA	Modular Observe-Orient-Decide-Act

NCW	Network Centric Warfare
NDP	Navy Doctrine Document
NEOPs	Network Enabled Operations
OODA	Observe-Orient-Decide-Act
OODB	Object-Oriented Data Bases
P	Process
PCT	Perceptual Control Theory
R-EL	Request-External Loop
RPD	Recognition Primed Decision
S	State
SADT	Structured Analysis and Design Technology
SU	Situation Understanding
T-EL	Transfer-External Loop

Distribution list

Document No.: DRDC Valcartier TM 2008-130

LIST PART 1: Internal Distribution by Centre

1	Director General
3	Document Library
1	Head C2 Decision Support System Section
1	Head Intelligence and Information Section
1	Head Systems of Systems Section
1	A. Auger
1	A. Benaskeur
1	A. Boukhtouta
1	A. Guitouni
1	A. Sahi
1	A.-C. Boury-Brisset
1	A.-L. Jousselme
1	C. Daigle
1	D. Gouin
1	F. Rhéaume
1	G. Thibault
1	H. Irandoust
1	J. Berger
1	J. Roy
1	Lcdr E. Woodliffe
1	Lcol M. Gareau
1	M. Allouche
1	M. Bélanger
1	M. Blanchette
1	Maj A. Lamontagne
1	N. Pageau
1	P. Valin
1	P. Maupin
1	R. Breton (Author)
1	R. Lecocq
1	S. Paradis
33	TOTAL LIST PART 1

LIST PART 2: External Distribution by DRDKIM

1 Library and Archives Canada
1 Director Research and Development Knowledge and Information Management (PDF file)

2 Director CORA
101 Colonel By Drive, Ottawa, ON, K1A0K2
2 Director Science and Technology (C4ISR)
Constitution Building, 305 Rideau St., Ottawa, ON, K1N 9E5
2 Director Science and Technology (Air)
Constitution Building, 305 Rideau St., Ottawa, ON, K1N 9E5
2 Director Science and Technology (Land)
Constitution Building, 305 Rideau St., Ottawa, ON, K1N 9E5
2 Director Science and Technology (Maritime)
Constitution Building, 305 Rideau St., Ottawa, ON, K1N 9E5
2 Director Science and Technology (Human Performance)
Constitution Building, 305 Rideau St., Ottawa, ON, K1N 9E5

14 TOTAL LIST PART 2

47 TOTAL COPIES REQUIRED

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (The name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Centre sponsoring a contractor's report, or tasking agency, are entered in section 8.) Defence R&D Canada – Valcartier 2459 Pie-XI Blvd North Quebec (Quebec) G3J 1X5 Canada	2. SECURITY CLASSIFICATION (Overall security classification of the document including special warning terms if applicable.) UNCLASSIFIED

3. TITLE (The complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S, C or U) in parentheses after the title.)

The M-OODA: Modelling of the OODA loop as a modular functional system:

4. AUTHORS (last name, followed by initials – ranks, titles, etc. not to be used)

Richard Breton ; Robert Rousseau

5. DATE OF PUBLICATION (Month and year of publication of document.) September 2008	6a. NO. OF PAGES (Total containing information, including Annexes, Appendices, etc.) 50	6b. NO. OF REFS (Total cited in document.) 33

7. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Technical Memorandum

8. SPONSORING ACTIVITY (The name of the department project office or laboratory sponsoring the research and development – include address.)

Defence R&D Canada – Valcartier
2459 Pie-XI Blvd North
Quebec (Quebec)
G3J 1X5 Canada

9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.) 11bu	9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)
10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.) DRDC Valcartier TM 2008-130	10b. OTHER DOCUMENT NO(s). (Any other numbers which may be assigned this document either by the originator or by the sponsor.)

11. DOCUMENT AVAILABILITY (Any limitations on further dissemination of the document, other than those imposed by security classification.)

Unlimited

12. DOCUMENT ANNOUNCEMENT (Any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in (11) is possible, a wider announcement audience may be selected.))

Unlimited

13. ABSTRACT (A brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual.)

The objective of the present document is to present a modified version of the OODA loop, the M-OODA. For the M-OODA loop to remain a useful tool in the context of documents defining the armed forces doctrine on C2, any modification has to keep explicit the high-level representation typical of the OODA loop, while accommodating dynamic and control concepts. The M-OODA incorporates explicit control and flow components more in line with the current understanding of military C2. It is based on a modular structure in which a module operates as a simple control system. A module is a task-goal directed activity formed of three core components (Process, State, and Control). A number of modules are structured in an OODA loop fashion and interconnected by feed-forward and feedback loops. The M-OODA model provides a compromise between that high level view of C2 decision-making, valued in military documents, and an expansion accommodating the basic C2 functions on information handling, processing, communicating and the coordination and direction in C2.

L’objectif de ce document est de présenter une version modifiée de la boucle OODA, la boucle M-OODA. Afin de préserver l’utilité de la boucle OODA pour représenter le processus décisionnel en C2, toute modification apportée doit préserver les bénéfices de la représentation des quatre grandes phases du cycle décisionnel tout en apportant plus de détails sur la nature dynamique de la prise de décision et les notions de contrôle. La boucle M-OODA inclut des composantes permettant de représenter les notions de contrôle et de transfert d’information (flux) plus conforme à la compréhension actuelle de C2. Elle est basée sur une structure modulaire dans laquelle un module, dirigé par les buts, fonctionne comme étant un système simple de contrôle. Pour représenter le cycle décisionnel en C2, des modules sont structurés selon la représentation classique de la boucle OODA. Ces modules, formés de trois composantes (Processus, État, Contrôle), sont interconnectés par des boucles de rétroaction et de transmission. Le modèle de la boucle M-OODA offre un bon outil de représentation du cycle décisionnel en C2, tout en fournissant plus de détails sur les fonctions de base en C2, telles que la manipulation d’information, son processus, et les principes de communication, coordination et direction en C2.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

OODA loop; Command and Control, Decision process; Cognitive processing; Effect-Based Operations; Decision modelling

Defence R&D Canada

Canada's Leader in Defence
and National Security
Science and Technology

R & D pour la défense Canada

Chef de file au Canada en matière
de science et de technologie pour
la défense et la sécurité nationale

DEFENCE R&D DÉFENSE

www.drdc-rddc.gc.ca