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Modelling approach for team decision-making

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Abstract

This document proposes a modelling approach to address the need for the development of team models. The modelling approach is based on guidelines and principles in addition of sets of building blocks and team functioning elements. To demonstrate the modelling capabilities, four different team decision-making situations are defined. These situations vary in terms of time pressure and complexity of the information to be processed by the teams. According to these four different models produced with the modelling approach, there are differences in terms of building blocks used to represent module architectures between models and the team functioning elements essential for optimal team functioning. With the varying conditions in the environment, a team may switch from one type to another. The comparison between the different models allows the evaluation of the benefits-costs of switching between the different decision-making types. This benefits-costs evaluation is based on building blocks used and team functioning elements included in the models. While the modelling approach still requires more validation studies, it shows interesting potential to identify requirements for training programs development, decision support system design and organizational changes.

Résumé

Ce document propose une approche de modélisation afin de permettre le développement de différents modèles représentant l'exécution de tâches en équipe. Cette approche de modélisation est basée sur un ensemble de guides et principes et des ensembles de bloc de construction et éléments de fonctionnement en équipe. Les capacités de modélisation sont démontrées à l'aide de quatre différents types de prises de décision par équipe. Ces quatre types sont définis en fonction de l'importance de la pression temporelle dans la situation et la complexité de l'information à être traitée par l'équipe. En fonction des quatre modèles produits à l'aide de l'approche de modélisation, on peut remarquer des différences entre ces modèles au point de vue des blocs de construction utilisés pour représenter les modules inclus dans les modèles et les éléments de fonctionnement en équipe essentiels pour le bon fonctionnement. Avec les conditions changeantes dans l'environnement, une équipe peut avoir à passer d'un type de prise de décision à un autre. La comparaison entre les différents modèles représentant les différentes situations permet l'évaluation des coûts et bénéfices liés au transfert qu'une équipe peut faire d'un type de prise de décision à un autre. Cette évaluation est basée sur les différentes architectures de modules ainsi que l'inclusion dans les différents types des éléments de fonctionnement en équipe. Bien que l'approche de modélisation requière encore quelques études de validation, cette approche démontre un potentiel intéressant pour l'identification de requis pour le développement de programmes d'entraînement, le design de systèmes d'aide à la décision et l'identification de changements organisationnels.

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Executive summary

Historically, to understand the execution of decision-making (DM) by a single person, the modelling approach has been used. The premises of both the normative and descriptive models have provided valuable insights for the development of training programs, and the design of decision support systems (DSS) for individual DM task. One may claim that there are substantial differences, from operational, structural and information processing standpoints, between the execution of a DM task by a single person and the one performed by a team. Consequently, using the individual DM models to develop training programs or to influence the design of DSS used in team environment could be misleading. It raises the need for the development models that represent the team dimension in the execution of the DM task. This document proposes a modelling approach that addresses this specific need.

The modelling approach, based on a modular architecture, includes concepts and guidelines from which the models are derived. A given team decision-making model is composed of different modules that represent the phases, functions or processes included in the DM task. The concepts included in the modelling approach are the basic module, the team building blocks and the team functioning elements. The basic module is the core of the model. This module is used to represent the components and properties of the subtasks included in the DM task. We propose that each subtask is structured in an input-process-state-control sequence. To represent the team dimension, it is necessary to identify the interaction between the units (agents) part of the team that are responsible for the execution of single or multiple processes which in turn produce single or multiple states. The team model is developed from the combination of different building blocks that represent a specific sequence of processes required by the task execution. In the modular approach proposed, a set of nine building blocks is defined from some general and mapping rules and principles. Finally, team functioning elements have also been referred as components, factors or dimensions that make a group of persons working as a team. In this document, we propose a set of six team functioning elements, which are human communication, tool communication, task balancing, task allocation, coordination and information distribution. These elements are seen to be essential for optimal team performance.

To demonstrate the modelling capabilities, different team decision-making situations are defined. These situations vary in terms of time pressure and complexity of the information to be processed by the teams. Four different types of team decision-making can be used to cope with the situations represented at the extremity of both the time pressure and diversity of skills continuums. These types are labelled “Autocratic” (Complex + High Pressure), “Democratic” (Not Complex + High Time Pressure), “Deliberative” (Not Complex + Low Time Pressure) and “Cooperative” (Complex + Low Time Pressure).

According to the four models produced with the modelling approach, there are differences in terms of building blocks used to represent module architectures between models and the team functioning elements essential for optimal team functioning. Both the autocratic and cooperative types include several team functioning elements while these elements are almost absent in the deliberative and democratic ones. The building blocks used to represent the modules architecture in the autocratic and cooperative types are also different. Finally, the comparison between the different models allows the evaluation of the benefits-costs of switching between the different decision-making types. It leads to the identification of DSS, training and organizational changes requirements to successfully support the benefits and cope with the costs associated to the switch between the different decision-making types. While the modelling approach still requires more validation studies, it shows interesting potential to identify requirements. It can also be included in the analytical process of task performance, coupled with a cognitive task analysis/cognitive work analysis (CTA/CWA), to identify the team dimension that is not usually covered with traditional task analysis methods.

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Sommaire

Historiquement, la compréhension de l'exécution d'une tâche de prise de décision par un être humain a été basée principalement par la création de modèles de prises de décision. Les prémisses découlant de ces modèles normatifs ou descriptifs ont fourni des renseignements essentiels au développement de programmes d'entraînement et au design de systèmes d'aide à la décision. Or, on peut prétendre qu'il y a des différences importantes, aux points de vue opérationnel, structurel et du traitement de l'information entre l'exécution de la tâche de prise de décision effectuée par une personne ou par une équipe. Par conséquent, les modèles représentant l'exécution de la tâche par une personne peuvent être inadéquats pour représenter l'exécution par équipe et, par le fait même, inutiles pour supporter le développement de programmes d'entraînement et le design de systèmes d'aide à la décision. Des modèles représentant l'exécution de la tâche de prise de décision en équipe sont donc essentiels. Ce rapport technique propose une approche de modélisation visant à répondre à ce besoin.

L'approche de modélisation, basée sur une architecture modulaire, inclut des concepts et guides à partir desquels les modèles sont dérivés. Un modèle donné de prise de décision en équipe est composé de différents modules qui représentent les différentes phases, fonctions ou processus inclus dans la tâche de prise de décision. Les concepts inclus dans l'approche de modélisation sont le module de base, les blocs de construction et les éléments de fonctionnement en équipe. Le module de base est l'élément principal des modèles. Il est utilisé pour représenter les composantes et propriétés des sous-tâches incluses dans la prise de décision. On propose que chaque tâche soit structurée dans une séquence entrée-processus-sortie-contrôle. Afin de représenter la dimension équipe, il est nécessaire d'identifier les interactions entre les unités (agents) constituant l'équipe. Un modèle d'équipe est développé par la combinaison de différents blocs de construction qui représentent une séquence particulière au processus requis par l'exécution de la tâche. Dans l'approche modulaire proposée, un ensemble de neuf blocs de construction est défini à partir de différentes règles et principes. Finalement, les éléments de fonctionnement en équipe peuvent être considérés comme étant des composantes, facteurs ou dimensions qui permettent à un groupe de personnes de travailler adéquatement en équipe. Dans ce rapport technique, on propose un ensemble de 6 éléments de fonctionnement en équipe. Ces éléments sont la communication entre humain, la communication entre outils, le balancement de tâches, l'allocation de tâches, la coordination et la distribution de l'information. Ces éléments sont considérés comme essentiels à une performance d'équipe optimale.

Afin de démontrer les capacités de l'approche de modélisation, différentes situations de prise de décision en équipe sont définies. Ces situations varient en fonction de la pression temporelle et la complexité de l'information à traiter. Quatre types de prises de décision en équipe peuvent être employés afin de composer avec les valeurs extrêmes situées sur les continuums de la pression temporelle et de la complexité de l'information. Ces types sont nommés "Autocratique" (Complexe + Pression Temporelle élevée), "Democratique" (Pas Complexe + Pression Temporelle élevée), "Délibérative" (Pas Complexe + Pression Temporelle faible) et "Coopérative" (Complexe + Pression Temporelle faible).

En fonction des quatre modèles produit à partir de l'approche de modélisation, on constate des différences au point de vue des blocs de construction utilisés pour représenter les architectures des modules et les éléments de fonctionnement en équipe inclus pour un rendement optimal.

Les types de prises de décision en équipe autocratique et coopérative incluent davantage d’éléments de fonctionnement que les autres types. Les blocs de construction inclus dans ces modèles sont également différents. Finalement, la comparaison entre ces modèles permet l’évaluation en matière de coûts-bénéfices pour le passage d’un mode de prise de décision à un autre. Cette évaluation conduit à l’identification des besoins en matière de programmes d’entraînement, de systèmes de support et de changements organisationnels afin de pleinement profiter des bénéfices et de minimiser les coûts associés au changement de mode. Bien que l’approche de modélisation requière encore plus d’études de validation, elle démontre un potentiel intéressant afin d’identifier les besoins. Elle peut être incluse dans le processus analytique d’exécution de tâche, associée avec une CTA/CWA, pour identifier la dimension équipe qui n’est généralement pas couverte par les techniques traditionnelles d’analyse de tâche.

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1. Introduction

Naturalistic environments, in which most of decisions are taken, are seen to be ill-structured, complex, with conflicting of competing goals. They are also characterized by the presence of high stakes and time pressure and multiple players. In order to cope with these factors, human has developed training programs and designed appropriate decision support systems (DSS). These solutions have been based on the comprehension of how a human makes decision in naturalistic and complex settings.

Historically, to understand the execution of decision-making (DM) by a single person, the modelling approach has been used. Several models have been proposed, the normative models to identify how an optimal decision should be reached and the descriptive ones to represent how human makes decision in complex environments. Normative models propose a norm; a formal process of weighting costs/benefits of a set of options that people should follow in order to reach the optimal and ideal decision. Descriptive models include a more psychologically valid description of the processes involved in a DM task. These models are based on a cognitive Human-Information Processing approach (HIP). In that type of approach, a system of cognitive HIP, like attention, short-term memory or declarative and procedural memory, are assumed to support cognitive activities.

For a review on the applicability of different DM models in complex environments such as the Command and Control (C^2), see Breton & Rousseau (2001). According to their conclusions, the Recognition Primed Decision (RPD) proposed by Klein (1993) seems to be the more appropriate to represent individual DM in complex environments. The RPD model relies heavily on a process of recognition of known patterns in the available information as a basis for deciding on an appropriate action. Human decision-makers, using their expertise, can immediately determine an acceptable solution from this pattern recognition process.

The premises of both the normative and descriptive models have provided valuable insights for the development of training programs, and the design of DSS for individual DM task. Nevertheless, even with the support of powerful and appropriate DSS or efficient training programs, an operator can rapidly be overloaded in stressful and complex environments like those inherent to C^2. A solution is to constitute a team that can be seen as a collection of individuals who must coordinate their thoughts and actions to reach a desired state from their initial state (MacCrimmon & Taylor, 1976). Dyer (1984) and Morgan, Glickman, Woodard, Blaiwes, and Salas (1986) identify a set of characteristics defining a team:

- a set of two or more individuals;
- a team has more than one source of information;
- interdependence and coordination among members;
- adaptive management of internal resources;
- team members share common values and goals;
- defined roles and responsibilities;
- task relevant knowledge.

Generally, teams are formed to improve the DM capacity and efficiency. According to Orasanu and Salas (1993), even if a single individual bears responsibility for the decisions, many participants contribute to the final product. They define team DM as the process of reaching a decision undertaken by interdependent individuals to achieve a common goal. They distinguish the team DM from the individual process by the existence of more than one source of information and the task perspective that must be combined to reach a decision.

There are substantial differences, from operational, structural and information processing standpoints, between the execution of a DM task by a single person and the one performed by a team. Consequently, using the individual DM models to develop training programs or to influence the design of DSS used in team environment could be misleading. It raises the need for the development models that represent the team dimension in the execution of the DM task. It follows that the modeling of the team DM task could help to understand the team aspect in the task execution. Such model should provide answers to these following questions:

- What is required for efficient team decision-making?
- What should be trained?
- What should be supported by appropriate systems?
- What types of team organizations should be required in a given situation?

A good deal of psychological research on decision-making is aimed at developing general models (i.e. not task or domain specific) to represent individual decision-making. Normative models provide, such as the Expected Utility theory, propose a norm, a formal process that people should follow in order to reach the optimal and ideal decision. Descriptive models, like the RPD model, include a more psychologically valid description of the decision-making process.

While it can be possible to develop generic models (e.g., RPD) representing individual DM task, the development of such general team DM model should be more challenging. One problem is that the decision process should be different between different team organizations. For instance, DM process of a C^2 team where the final decision is often let to a team leader should be different than the one used by a jury to reach a consensus over the final decision. Moreover, the decision process used by a given team should also be different depending of the characteristics of the situation. As an example, in a C^2 environment marked by important time-constrains, a hierarchic mode of teamwork where the leader is in charge of the final decision could be adopted while in less stressed ones, a more cooperative mode could be possible.

It results that generic team DM models could not be representative of all different sequences of processes. This single generic team DM model could be too general and then, useless to provide valuable insights required to develop training programs, systems design and team reorganization requirements. This raises the need for task or domain-dependent team decision-making models. This need brings another challenge to researchers. The development of a given team DM model for every situation or particular task could be time-consuming and very costly in terms of effort. There should also be a great deal of variability in terms of level of granularity and exactness between models, which in turn should affect the level of quality of the requirements identified from these models. In order to overcome these problems, we propose a modelling approach that provides guidelines and principles from which, different team DM models representing different situations can be developed.

2. The Modelling Approach

The modelling approach, based on a modular architecture, includes concepts and guidelines from which the models are derived. A given team decision-making (TDM) model is composed of different modules that represent the phases, functions or processes (hereafter labeled subtask) included in the DM task. The next section describes these concepts and guidelines.

2.1 The Concepts

The concepts included in the modelling approach are the basic module, the team building blocks (BB) and the team functioning elements (TFE).

2.1.1 The Basic Module

The basic module is the core of the model. This module is used to represent the components and properties of the subtasks included in the DM task. We propose that each subtask is structured in an input-process-state-control sequence as defined by the simple module presented in Figure 1.

A module represents a task-goal directed activity supported by a number of components. A module can be seen as the basic structural element of a goal-directed system. Consequently, the module has components whose function is to produce the expected state following the appropriate process according to preset criteria. On top of that, a module has elements whose function is to interact with other modules and the general environment.

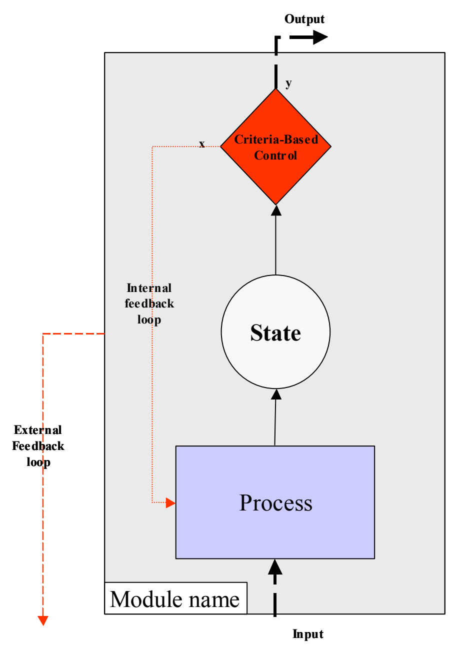

Figure 1. *The Structure of the basic module.*

The module is formed of the module name, three basic components (process, state and control), two feedback loops and an input/output. The module name corresponds to the particular subtask included in the DM task. The name of the module reflects the general or ultimate goal (G) of the module. For instance, if the goal of the process is to gather data from the environment, then, the module can be labelled Data Gathering. 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.

In most cases, inputs (I) are outputs from other preceding modules. It can obviously be information or data picked from the environment. The process (P) is the core active component of a module. It is a goal-directed action applied on an object. 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, processes such perceive, sense, understand, identify, organize, select, act and plan can be used to represent a module goal-oriented activity. This goal is achieved by an agent, which can be a human, an automaton or a combination of both.

The state (S) 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 general properties of state are also defined according to the module goal.

The criteria-based control (C) 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 depending on task-goal criteria. Since they are goal related, the control criteria should be different from one module to another.

The Output (O) 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. Outputs with high level of familiarity can initiate automatic process in subsequent module.

The internal feedback loop (IL) 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. The external feedback loop (EL) enables communication between modules. We label target module, the module towards which the EL is directed. There are two kinds of EL: 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 to a target module in order to enable an adequate or maximal state. The request is connected to the target module control component. It can, if necessary, redefine the criteria included in the control component that define the state. 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. It produces a form of broadcasting 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 next Table gives a summary of the parameters defining each component of a module.

Table 1. Summary of the parameters associated with each component of the Basic Module

Component	Parameters
Module name	G: [input, action, desired state, control criteria]
Input	I: [physical signal, state, non-OODA input]
Process	P: [action verb, object, agent].
State	S: [object, representation, goal-determined properties, process-specific properties]
Control	C: [time, quality, goal-related criteria].
Output	O: [current State]
Internal loop	IL: [state quality criterion, state completeness criterion, update monitoring]
External loop	R-El: [time, information criterion, number] T-El: [State status, control status].

Figure 1 presents a module including a single process producing a single state controlled by a single set of criteria. The execution of this process can be under the responsibility of either a human or an automated system. The team dimension is absent from that representation. However, from that module, team BB that represent the team dimension can be derived.

2.1.2 Team Building Blocks

The basic module can be seen as the simplest unit of the modular approach. It represents a single agent that produces a single state from a process execution. The quality of this state is controlled by a single criteria-based component. To represent the team dimension, it is necessary to represent the interaction between the units part of the team that are responsible for the execution of single or multiple processes which in turn produce single or multiple states. These team units or hereafter-called building blocks are used to develop team decision-making models. Then, a given model is developed from the combination of different BB that represent a specific sequence of processes required by the task execution. In the modular approach proposed, a set of nine BB is defined. These BB have been derived from some general and mapping rules and principles.

General rules:

- Every building block follows the architecture of the basic module presented in Figure 1. It is always composed of at least one Process, one State and one Control-based criteria component.
- The process box represents the execution of a given process by a single agent on one or multiple input sources in order to produce a given state.
- The number of Process equals the number of agents involved in the module execution (# Process = # agents).

General mapping rules:

The team BB, presented in Table 2, are the results of different mapping between the components. The possible mappings (4) are stated as follow:

- (1:1): one-to-one mapping between the module components;
- (1:M): indicates a one-to-many mapping;
- (M:1): indicates a many-to-one mapping;

- (M:M): indicates a many-to-many mapping.

Other rules are used to define the possible mappings between the module components in order to derive the set of BB:

- Possible mappings between Input and Process:
  - A single Input is fed into a single Process (1:1);
  - A single Input is distributed to many Processes (1:M);
  - All different Inputs available in the environment can be distributed to all available Process (M:M). However, a single Process will always be responsible for the processing of a particular type of inputs. In other words, process can be seen as been specialized in the processing of a particular source of inputs. The other Inputs fed into this process can be seen as secondary or complementary information sources.
- Impossible mappings between Input and Process:
  - Multiple Inputs cannot be feed into a unique all-purpose Process as primary information sources (M:1 is impossible). A Process is not multi-purpose.
  - Possible mappings between Process and State:
  - A Process can produce a single State (1:1);
  - A Process can collaborate with others (i.e. fusion process) to produce a unique shared State (M:1).
- Impossible mappings between Process and State:
  - A same Process cannot produce many different States (1:M is impossible). A Process is not seen as been multi-purpose and then cannot produce different types of state. Then, a particular Input fed into a given Process should always produce the same Output;
  - A many-to-many (M:M) mapping is impossible since a single Process cannot be involved in the production of different state. Note that in the case of the fusion process, many processes are collaborating but only one fused state is produced.
- Possible mappings between State and Control:
  - A State is controlled by one Criteria-based component (1:1);
  - Many States can be related to one generic Control (M:1).
  - Possible mappings between State and Control:
  - A State cannot be related to many different Controls (1:M is impossible). All required criteria are included in one Control;
  - Many States cannot be related to many different controls (M:M is impossible) since a given State is always controlled by one Control component.

Table 2 presents a set of three BB defined from the principles, rules and mappings previously stated. These BB (1, 1a, 1b) are labelled independent BB. They represent a team of three agents (humans or systems) producing each a State controlled by a specific Control component (see Figure 2). Since they are controlled by different set of criteria, the production of different states and their transfer to subsequent modules can be asynchronous and independent. The resulting States may also differ significantly in terms of quality, uncertainty and accuracy.

Table 2. Mappings and rules used to define the independent building blocks

#	Rules	I-P	Rules	P-S	Rules	S-C
1	A specific I is related to a specific P	1:1	Each P produces a S	1:1	Each S is controlled by a specific C	1:1
1a	One I is distributed to many P	1:M	Each P produces a S	1:1	Each S is controlled by a specific C	1:1
1b	Many Is are distributed to many Ps	M:M	Each P produces a S	1:1	Each S is controlled by a specific C	1:1

The distinction between these three structures concerns the distribution of the inputs. In the first building block (left side), specific inputs are allocated to specific or specialized process. In the second (center), a single input is distributed to all processes. In the third (right side), all processes are considering a primary source (straight arrow), but have also access to other available sources (doted arrows) as complementary information.

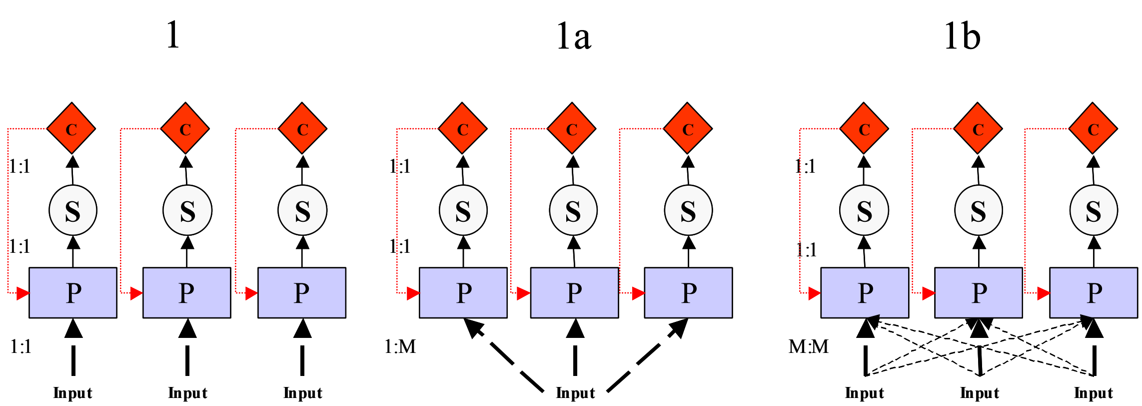

Figure 2. *The independent building blocks.*

Table 3 defines the mappings of the synchronization BB (2, 2a, 2b). In these ones, each agent (3) produces a specific State. Contrarily to the independent BB, these States are all controlled by the same set of criteria. As a result, their transfer to other subsequent modules is synchronized. Also, the unique set of criteria raises the level of homogeneity in the quality of the States that are fed into next modules as three distinct entities.

Table 3. Mappings and rules used to define the synchronization building blocks

#	Rules	I-P	Rules	P-S	Rules	S-C
2	A specific I is related to a specific P	1:1	Each P produces a S	1:1	All Ss are controlled by a unique C	M:1
2a	One I is distributed to many P	1:M	Each P produces a S	1:1	All Ss are controlled by a unique C	M:1
2b	Many Is are distributed to many Ps	M:M	Each P produces a S	1:1	All Ss are controlled by a unique C	M:1

The distinction between the synchronization BB lays in the distribution of the inputs (see Figure 3).

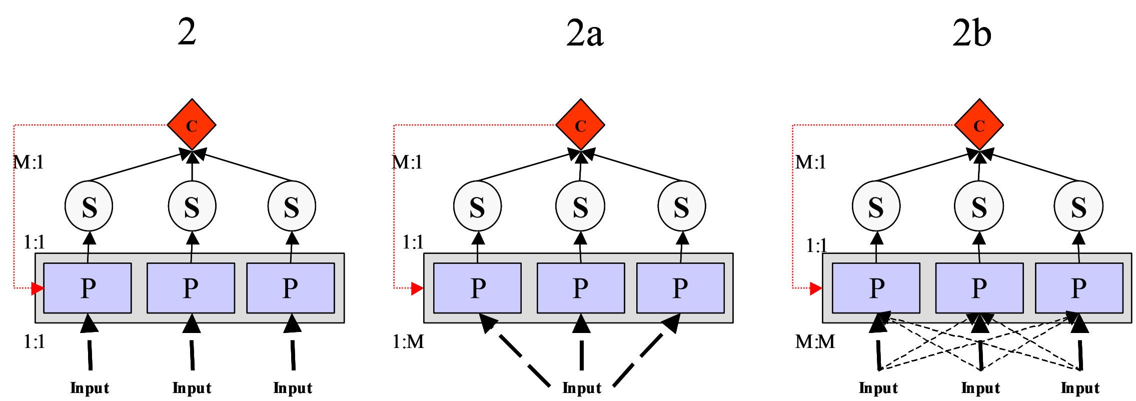

***Figure 3.** The synchronization building blocks.*

Table 4 defines the mappings of the last three BB (3, 3a, 3b) labelled collaboration BB in which agents are collaborating to produce a unique State. The unique Stare requires a unique set of criteria. The fused State is fed as a unique one into next modules.

Table 4. Mappings and rules used to define the collaboration building blocks

#	Rules	I-P	Rules	P-S	Rules	S-C
3	A specific I is related to a specific P	1:1	All Ps are collaborating to produce a single S	M:1	The fused S is controlled by one C	1:1
3a	One I is distributed to many P	1:M	All Ps are collaborating to produce a single S	M:1	The fused S is controlled by one C	1:1
3b	Many Is are distributed to many Ps	M:M	All Ps are collaborating to produce a single S	M:1	The fused S is controlled by one C	1:1

Here again, the distinction between the collaboration BB lays in the distribution of the inputs. Figure 4 presents these BB.

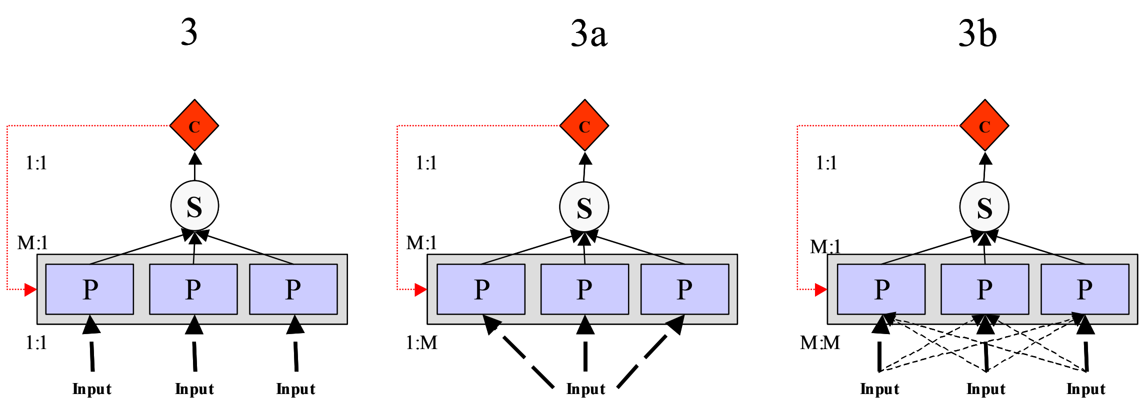

Figure 4. *The collaboration building blocks.*

From the combination of appropriate BB, the sequence of subtask execution and the information exchange within and between modules can be represented. However, the architecture resulting from the combination of the blocks does not stress the elements that make a particular team more efficient than another. To fully demonstrate the team dimension, Team Functioning Elements (TFE) must be incorporate within these BB. The set of TFE, described in the next section, is the one proposed by the NATO TG006, IST-019 working on the modelling of organization and decision-making. The set includes Human Communication (HC), Coordination (Co), Task Allocation (TA), Task Balancing (TB), Tool Communication (TC) and Information Distribution (ID) as being essential and critical TFE.

2.1.3 Team Functioning Elements

TFE have also been referred as components, factors or dimensions that make a group of persons working as a team. Following a literature survey on teamwork, Dickinson and McIntyre (1997) propose a set of 7 components that are: Communication, Team Orientation, Team Leadership, Monitoring, Feedback, Backup Behavior, and Coordination. Within the TADMUS (Tactical Decision Making Under Stress) project, Smith-Jentsch, Johnson and Payne (1998) provided an original set of eight team dimensions. After an evaluation of these eight dimensions, the set was reduced to four that proved easier to measure. These four dimensions are: Information Exchange, Communication, Supporting Behavior, and Team Initiative/Leadership. Marks, Sabella, Burke and Zaccaro (2002) consider Coordination and Backup Processes as two important teamwork elements.

In analyzing these different lists, one may observe that components referring to the same activity are used with interchanging labels. For instance, Backup Behavior, Supporting Behavior and Backup Processes may refer all to the same meaning that can be defined as the support of other team members' actions.

Most of components, factors or dimensions found in the literature are related to the relationship between humans. However, the constitution of team to execute a DM task may have repercussions on the way the task is executed and the technological systems used by the team members. Concerning the task, it is critical to identify how the overall task can be decomposed in meaningful units and distributed according to the skills available within the team. About the systems, they must be designed to support the execution of these units of task and to ease the use of the different human skills without preventing teamwork. Then, there is a need to identify TFE that cover not only the human dimension but also the task and the system ones. In other words, TFE are essential to make sure that the whole task is well performed by the team and the technological systems or tools are interoperable.

The NATO TG006, IST-019 group has identified a list of TFE that covers not only the human aspect but also the task and the tool ones. This list has been developed using the TRIAD model proposed by Breton, Rousseau & Price (2001). The TRIAD is composed of three nodes (Task-Tool-Human) that are interrelated to form a network. The specialists involved in the design process are introduced through a specific node of the TRIAD network. For instance, human factor specialists are introduced through the human node and system designers by the tool one. This TRIAD identifies, for these specialists, their axis of expertise (their roles and mandates), their hidden axis (their limitations) as well as the interactions between these experts. The primary axis of expertise for the human factor specialists is the human-task one. The tool-task nodes define their hidden axis. To represent the team dimension, recursive arrows have been added to the elements to indicate the presence of multiple team members interacting together in order to execute a series of interconnected tasks that lead to a decision. These different team members have access to a set of tools independent or interconnected.

A representation of information sources has also been added within the TRIAD to represent the inputs considered in the execution of the different tasks part of the overall DM one. It also shows the links between these inputs, which are of nature of data, information, knowledge and understanding, and the two other elements of the TRIAD. These links illustrates the importance of the presence of different skills within the team the importance of appropriate tools to process the different types of information. From this TRIAD model, six TFE have been proposed. Figure 5 shows the distribution of HC, Co, TA, TB, TC and ID within the team TRIAD model. These TFE are described in more details below.

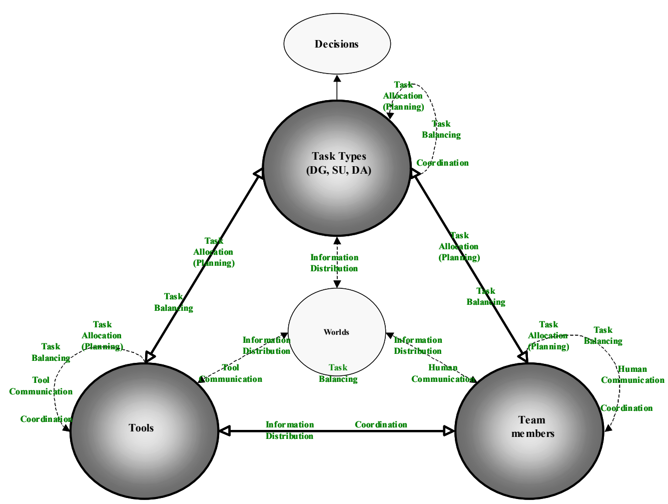

Figure 5. *The TFE in the Team TRIAD model proposed by the NATO TG006, IST-019 group.*

2.1.3.1 Human Communication

Communication is probably the most unanimous team elements among the different papers in the literature addressing the team dimension of DM. According to Denson (1981), McIntyre, Salas, Morgan, & Glickman (1989) and Dickinson & McIntyre (1997), communication is a major component of teamwork processes. Communication involves the active exchange of information between team members. It seems that the label *"communication"* is generally used, in literature, to represent the activity of information exchange. As a result, the information exchange dimensions proposed by Smith-Jentsch et al. can easily be included in the communication element. These exchanges can take various forms such as feedback, gestures, and non-verbal language. The feedback component in the Dickinson & McIntyre list can also be included in the communication element. Providing feedback to other team members can be seen as a certain form of communication. To be successful, a team must adapt and learn from its performance. This adapting and learning process require the giving, seeking and receiving of feedback among team members. While they could not be included, team orientation and leadership, from the Dickinson & McIntyre list could also be related to the communication element. The team orientation component includes, for instance, the nature of the attitudes that team members have toward one another. Attitudes are, most of the time, important aspects defining the type of communication between persons.

In the Team TRIAD model of Figure 5, HC is related to the recursive arrow connected to the team members elements to illustrate the impact of this element on the interaction between the team members. It concerns the way team members are communicating altogether. Since it concerns the exchange of information, it is also related to the link between the team members and the sources of information. This is more related to what it is communicated among the team members.

2.1.3.2 Tool Communication

In the NATO list, a slight distinction is made between the exchange of information between humans and the exchange of information between tools. Communication between humans includes non-verbal language and social considerations that are not relevant to define the communication process between the tools. The TC element concerns, in addition of the exchange of information, the concepts of interoperability, data exchange and information exchange protocols and standards between tools. It can be seen as the counterpart of the HC element. It is then related to the recursive arrow that represents its impact on the ways the tools are communicating among them. It is also related to the link between the tools and the sources of information. Similarly to the HC, it concerns the information content communicated among the tools.

2.1.3.3 Coordination

In literature, more labels can be used to define the coordination element. This element concerns the activities between team members. It is related to the merging, in a logical and coordinated manner, of the actions of different individuals to execute adequately a task.

Team orientation and leadership, from the Dickinson & McIntyre list could be related to the coordination element. The way the actions are coordinated is highly related to the team orientation. They also propose the team leadership component, which includes direction and structure provided by formal leaders as well as by other team members. These structure and direction are the basis for an adequate coordination of the actions of every team members.

Team leadership is also a dimension considered in the list provided by Smith-Jentsch et al (1998).

Dickinson & McIntyre propose two other components that can be included in the coordination element. These components are monitoring and backup behavior. They consider monitoring as the observation and awareness of activities and performance of other team members. Obviously, the monitoring component is essential for one individual to adequately coordinate his actions with those of another team member. They consider backup behavior as the capacity of helping other team members in the execution of their tasks. Here again, it is an important component of teamwork for an adequate coordination of the actions. This component is also proposed by Smith-Jentsch et al, (1998), labelled as supporting behavior, and by Marks et al, (2002) labelled as backup process. Finally, another dimension or component, proposed by Smith-Jentsch et al, can be included in the coordination element. This dimension is the team initiative. Team initiative can provide guidance or suggestions and can define priorities, which are necessary to adequately coordinate the actions within the team. Figure 7 presents the distribution of the different components and dimensions within the Communication and Coordination elements.

The NATO list provides a slight distinction to this TFE. While in literature it is mostly restricted to the coordination of human behaviors, the NATO list is extended to the coordination of technological systems or tools' actions. The basis under this distinction is that the actions of both team members and technological systems have to be properly coordinated to execute adequately the tasks. Then, it considers the recursive arrows related to each element of the Team TRIAD. Since technological systems are an integral part of the team, they must also be properly coordinated with both the other tools and the team members. The Co has also an impact on the link between the tools and the team members.

2.1.3.4 Task Allocation

A team is needed when one individual cannot handle the task workload within the period of time available in the situation. One way to solve this problem is to subdivide the workload and distribute it to different team members. The subdivision of the workload is obviously made with the subdivision of the general task into units of subtasks. To be executed adequately, these units may ask for different types of expertise. Consequently, these units of subtasks must be allocated to team members owning required skills and expertise. The TA element is related to the role and responsibilities of every team members. Instead of being allocated to different experts, it is possible that some units of subtask being allocated to specific technological systems. Depending of the nature of the subtasks, it can either be allocated to a human expert, an automated system or a human expert with the support of an appropriate support system. In case of automation, the TA element defines the roles and responsibilities of the automated tool. TA is an important TFE since it defines the optimal allocation of the subtasks to the team members or to support/automated systems.

Within the Team TRIAD, TA is related to both the tools-tasks and team members-tasks links. Depending on the nature of the tasks and the skills required to perform them, they may be allocated to humans, automated tools or both. TA has obviously an impact on the interaction between team members. It has also repercussions on the way to tools are interacting together in order to execute harmonically the different tasks. Finally, TA influences the way different tasks are interconnected. Then, TA is related to the recursive arrows of all the three elements. It may be important to allocated tasks that are closely interconnected to the same agent, team members or tools. A particularity with this TFE is that it does not intervene during the execution of the tasks but rather during the planning process.

2.1.3.5 Task Balancing

The allocation of subtasks to team members or automated/support system is mostly done during the planning process. However, in most circumstances, situations may not evolve as planned. Some reorganizations or task balancing may be required. For instance, it may happen that one team member being much more overloaded than its teammates. The TB element is related to the reallocation of subtasks among the team members in such a way that workload is better distributed. This balancing process happens during the execution of the subtasks and then implies that certain decision-making processes should be able to be reallocated. This demands a certain level of adaptation in the execution of tasks of the individual team members. Cannon-Bowers & Salas (1997) consider that the capacity of dynamically reallocating the functions within the team is a good measure of the team performance. The TB element should be seen as a reacting process to non-expected situations of overload.

TB is obviously a certain form of TA. Consequently, it influences all the interactions related to the TA element. However, there is one major distinction between these two TFE. TA happens during the planning process. TB happens during the execution of the tasks in the operational context and it is seen as a reactive procedure to overcome tools failures and breakdowns and overload problems. As a result, TB considers sources of information that are not related to the decision-making task per se. For instance, information from the monitoring of the team performance, which is a different task than the decision-making one, is critical to detect problems in the team performance. This information can be seen as the discrepancy between the actual team performance and the expected one. Then, such information is not available in the planning process since the question of team evaluation is irrelevant at that time.

2.1.3.6 Information Distribution

The inclusion of the information element within the TRIAD model raises the importance of information distribution in the tasks execution. To execute a task, appropriate information sources must be available. It must also be distributed to agent (team members, tools or both) owning the required skills. Then, ID concerns the three relationships between the information sources and the tasks, tools and team members elements. Since, most information sources are presented through technological displays to team members, this element also concerns the relationship between the tools and team members elements. Notions such those related to human-computer interaction and displays concepts are part of the link tools-team members.

The identification of the team functioning element is a step forward in the understanding of the team dimension in the decision-making task. Another step is to understand their integration within the overall task organization.

2.1.4 The construction of team module

The foundations of the BB lay in the basic module. The elements of the basic module are multiplied to represent the different team members or agents. Each Process represents an agent. These different Processes produce one or more States that are controlled by either related Control components or by a general one. The label puts on the Process component should represent the goal of the module. It could be possible to combine two or more BB to represent a more complex team module. In that complex module, it could be possible to put different labels on the Process components to illustrate different functions within the module. These different functions should be in line with the ultimate goal of the module. However, it may be more appropriate, for a matter of simplicity, to decompose this complex module into more specific ones representing each a given subtask executed by the team.

As an example of such combination, Figure 6 shows a team module that represent the information fusion activity. In that module, the building block representing independent processing is combined with the basic module. In the first layers, three agents (human or sensors) are sensing the environment in order to gather the information. In the next layer, the States resulting from the sensing process are fed into a unique Fusion Process that produces the Fused State. The ultimate goal of this team module could be the construction of a situational picture from complex and multi-sourced information. This large and general goal could include both sensing and fusion processes. However, it could be more appropriate to decompose this module, one illustrating the sensing process and the other the fusion one.

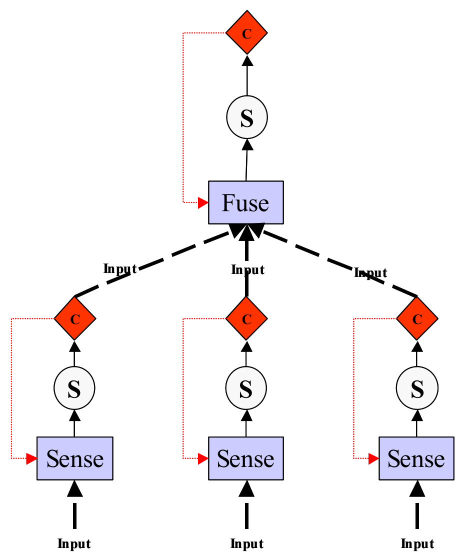

Figure 6. *The team module representing the fusion activity.*

2.2 The Guidelines

In the preceding sections, we have presented a set of tools (basic module, building blocks and team functioning elements). In the next sections, we describe how to use them in order to build team module and then, team DM models representing specific situations. To build a situation-dependent team model, these two basic steps should be executed:

- Identifying generic goal-related subtasks included in the DM task;
- Identifying specific situations in which the team must execute the task;

2.2.1 The identification of goal-related phases in the DM task

To develop a given team model, the first step is to identify the subtasks executed by the team in order to complete a given task. Obviously, task analysis techniques such as the Cognitive Task/Work Analysis (CTA/CWA) can be used to identify these subtasks.

Among the similarities between the different generic models (normative and descriptive) of DM, all seem to agree that the identification and implementation of a decision follows the perception of information from the environment and its analysis and understanding. These phases are compatible with the ones included in the classical version of the Boyd's OODA loop. Boyd identifies four processes: Observe – Orient – Decide – Act, organized into a loop. The OODA loop has been extremely used to represent C^2 activities typical of military decisions or of other complex high-risk time-stressed activities like aircraft piloting or fire fighting. It has the benefit of simply representing the decision cycle. It also provides taxonomy of the different phases included in the DM process. Problems start with the OODA loop when it is used as a descriptive model of DM. Its use as a descriptive model is limited by three basic difficulties:

1. It has no representation of the feedback or feed-forward loops needed to effectively model dynamic DM.
2. It is a very high-level representation with abstract concepts that do not provide the kind of details needed for the OODA loop to be used as an analytical tool for improving DM.
3. It is a strict sequential model with a single entry point and a single sequence of processes that cannot adapt to different levels of expertise in DM and to the diverse task context existing in real situations.

To overcome these problems, many loop alternatives have proposed. Breton & Bossé (2001) have proposed a version of the OODA loop including an iteration process between the Observe and Orient processes in order to overcome the sequential problem and to represent the dynamic nature of the task. Bryant (2004) proposes a cognitive alternative to represent C^2 DM task with his CECA model (Critique-Explore-Compare-Adapt). Among the benefits of this model, it represents the DM task as a goal-directed process. It also provides a top-down perspective to the cycle, which allows the inclusion of the commander's intent in the decision cycle. This model raises the importance of mental models as being the core of individual DM.

Rousseau & Breton (2004) also address these issues with a model that is closer to the original version of the loop than the CECA model. They propose a modular version of the OODA loop that extent the iterative and dynamic notions with feedback and feed-forward loop. The structure of this loop, called the M-OODA loop, lays in the basic module presented in Figure 1 (see. p.3) of this document. Figure 7 presents the Rousseau & Breton M-OODA loop model.

The M-OODA loop proposed by Rousseau & Breton is largely based on the information processing view proposed late in the seventies by Atkinson & Shiffrin (1968). It is also compatible with views of Hinsz (1990) and Duffy (1993) that consider teams as information processors.

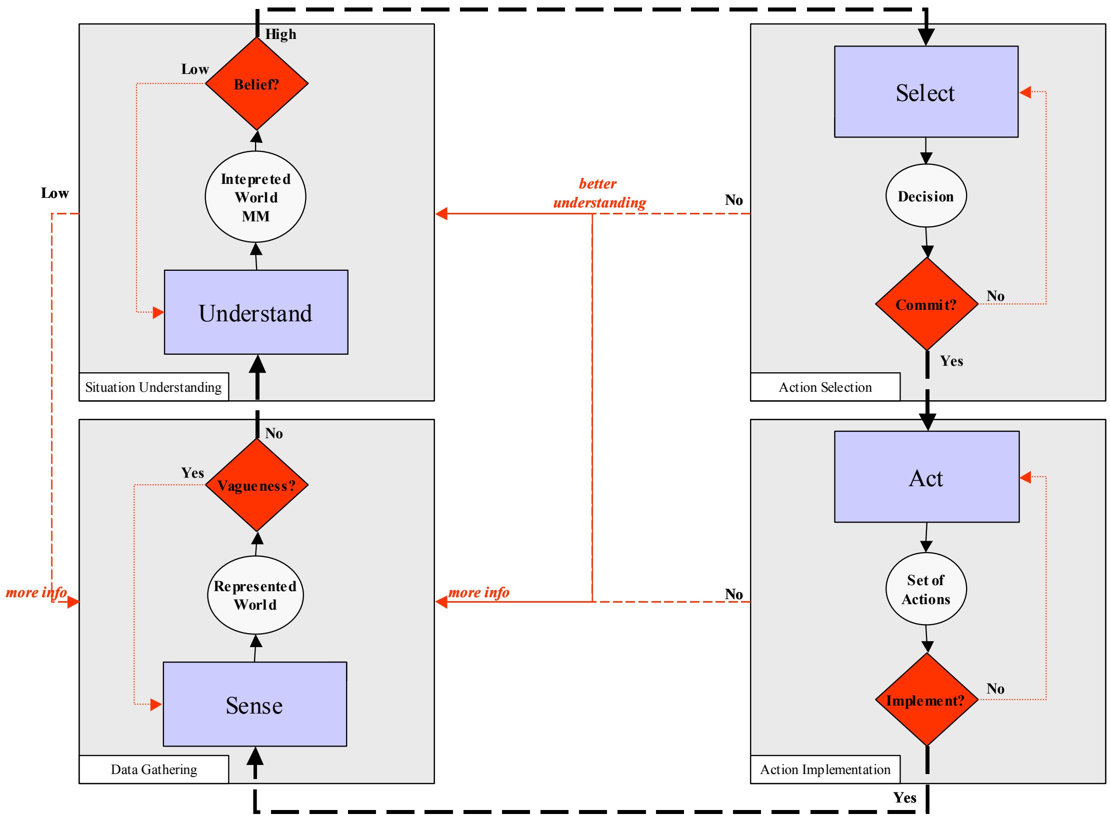

Figure 7. *The M-OODA loop (Rousseau & Breton, in preparation).*

Some advantages are identified with this type of version of the OODA loop. In the M-OODA loop, iteration processes are added within and between all the different modules part of the process. These feedback loops make possible backward communication between its parts. These loops have two purposes. First, within a module, they support an iteration request based on a set of criteria included in the control component. Second, they enable communication between the different modules. With these loops, the flow of activities in the M-OODA loop model is dynamic and multi-directional.

From Rousseau & Breton M-OODA loop model, four different subtasks can be identified. This list of subtasks is in line with the four processes proposed with the classical version of the OODA loop. Based on these processes, the subtasks in the M-OODA loop are identified with an action and an object on which the action is applied. For instance, Observe of the classical version becomes Data Gathering (DG) in the M-OODA loop. It is more specific and does not refer implicitly to a very general perception process whose meaning is vague. It is the same with the other three processes included in the loop. Moreover, the new labels avoid the inclusion of a Decide process within a DM model. That can induce some confusion since decision carries two very different meanings within the same very simple model. It always possible to argue about the difference between the Decide component and the over-all DM process but we consider that is a better solution to simply define the Decide process as one of Action Selection (AS), and keep the concept of Decision to refer to the whole M-OODA loop model.

Then, in a goal to provide more specific and non-confusing labels, Rousseau & Breton propose the terms presented in Table 5 to identify the subtasks included in the M-OODA-loop.

Table 5. Modifications to the OODA loop Processes labels proposed by Rousseau & Breton

Original OODA loop processes	**M-OODA loop processes Object-Action**
OBSERVE	DATA-GATHERING (DG)
ORIENT	SITUATION-UNDERSTANDING (SU)
DECIDE	ACTION-SELECTION (AS)
ACT	ACTION-IMPLEMENTATION (AI)

Rousseau & Breton offer a detailed but non-exhaustive description of the core components of each module (presented in Table 6). These terms are different possibilities that could be plugged into an appropriate module in order to describe the activity of the module. They have made an attempt at describing the specificity of each core component within each module.

Table 6. Labels used to identified the module and its components.

Module	Process	State	Control
Data Gathering	Sense, encode, register, data translation, transduce, scan, fuse, detect	World representation, scene organization, multimodal-integration	Vagueness, completeness, fuzziness
Situation Understanding	Understand, identify, categorize, classify, organize, schematize, recognize, form hypothesis	Mental model, schema, episode, familiarity estimation,	Belief in interpretation, familiarity of schema, uncertainty on meaning
Action Selection	Select, choose, identify options, apply rules, consult	Decision, list of actions (COAs), risk evaluation, expected gain, selection rules	Risk assessment, completeness of options, gain estimation, situation familiarity
Action Implementation	Act, planning, resource management, constraints identification, project management	Set of Actions, schedule, milestones, plan, mission, orders	Feasibility, acceptability, resource availability

In the M-OODA loop, the default sequence is similar to the one suggested by the classical version of the loop. Furthermore, in most circumstances, the loop is also initiated with the DG process. However, in the M-OODA loop, the initiation is not restricted to this one. In fact, all four modules can initiate it and serve as an entry point. For instance, a commander may have a feeling (feeling not triggered by any information from the environment) that something significant is currently happening in his environment. He may then send a request for more information to the DG module in order to verify confirm or infirm his feeling. In this situation, the decision cycle is initiated by the SU module that includes commander's mental model and intent. Adding the possibility of multiple entry points to the model has also an impact on the sequence from the modules is put in action. In our example, iterations between the DG and SU modules should happen before reaching the decision phase.

2.2.2 The identification of specific situations in which the team must execute the task

To summarize the modelling approach:

1. The subtasks included in the modeled task must be identify;
2. Specific situations in which the task is executed must be defined;
3. BB are used to represent the execution of these subtasks;
4. TFE are included to show the team dimension in the execution of the subtasks.

Appropriate task-oriented team DM models can be derived to represent different team executions. Then, it is essential to define the general situations in which the team DM task is executed. Details on the environments factors such as time constraints, complexity, types of information available and required and team organizations are all characteristics to be identified.

In the next sections, we define four general situations requiring the DM task to be executed by a team. These hypothetical situations are used to show our modeling approach. They vary along two variables that are the time pressure (low or high) and the need for diverse skills to cope with the complexity of the situation (low or high).

A team is often required to cope with the presence of important time constraints. These constraints can make the execution of the task by one individual somehow difficult. Time constraints can be defined by the ratio between the time available in the situation and the time required to execute the task. For instance, in a DM context, a time constraint is the difference between the time available and the time required to perform a decision task (Rastegary, & Landy, 1993). In addition to these externally imposed constraints, a person may internally impose to itself the obligation to accomplish more and more tasks in an ever-shorter amount of time (MacGregor, 1993). Breton & Rousseau (2001) consider that this particular type of time constraints can be felt without the presence of time pressure and varies among situations and people.

Obviously, the importance of a time constraints, internally or externally imposed, is largely dependent to the time required to cope with all the task workload. In other words, in a time-stressed situation, an individual may not be able to cope with the workload within the available period of time. A solution may be to distribute the workload among team members in order to execute the task within the available period of time.

The second variable concerns also to the task workload. However, this constraint is related to type of skills required to handle this workload. It may be possible that the workload requires different skills and expertises owned by different individuals. In that situation, while the time may not be an issue, the constitution of the team may be justified by the allocation of parts of the workload requiring specific skills to different team members owning these skills.

Within a given team, it is possible that different team members may work under more or less important time pressure. An efficient team would be one that allocates adequately the tasks among its team members in order to reduce the workload and time pressure factors. This task allocation process must be done in function of the expertise, skills and personality traits available within the team.

Our list of situations from which we demonstrate the modelling capacity of our approach is inspired from a list proposed by Vroom & Yetton (1973). They propose three team DM types. An autocratic one is used when a team leader, after obtaining all necessary information from the other team members, decides on a solution alone, without sharing the solution process. A consultative mode is adopted when the team leader shares the problem with the other team members and gathers ideas and suggestions before making the decision alone. These first two types of team decision-making can be typical of military command and control environments in which the final decision is often under the responsibility of a commander. A participative type is used when all team members share the problem, are involved in the generation and evaluation of potential solutions and reach a mutual agreement on the chosen solution. A decision taken by a jury in a trial can be seen as a good example for this third type.

Based on Vroom & Yetton list, we propose a set of four team DM organizations. These types can be used to cope with the situations represented at the extremity of both the time pressure and diversity of skills continuums (see Figure 8). These types are labelled “Autocratic”, “Democratic”, “Deliberative” and “Cooperative”.

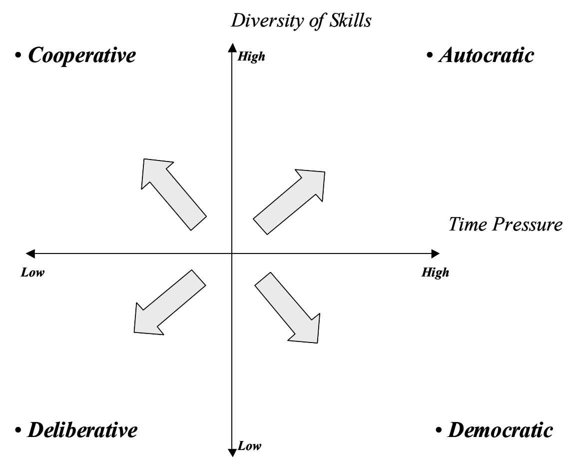

Figure 8. *The illustrations of four team DM types.*

The autocratic type is similar to the one proposed by Vroom & Yetton. All three others are a breakdown of the participative mode of Vroom & Yetton list. In the democratic mode, different persons analyse the situation and vote on the best alternative. This mode can be used in time-pressed by not complex situation. The vote taken by different team members reduces the effect of human errors and biases. In the deliberative mode, team members share their thoughts and opinion on the situation in order to reach a consensus over the best solution as possible. They are not constraint by time and may take all the time required in order to reach the optimal solution. The best example of this mode is the decision process used by a jury.

Finally, the cooperative mode is used when different team members with different expertises shares their opinions in order to reach a consensus. The main difference with the deliberative mode is that the information analysed ask for different expertises.

Obviously, the list of these four general types of team DM is not exclusive or exhaustive. They represent team organizations that can be used in extreme time-pressed (low or high) and complex (low or high) situations. These types constitute our sample in which the modelling approach will be applied to represent the team dimension. In the next sections, we provide more details on these types and propose a detailed situation to represent them.

For each models, the Action Implementation module is not modified. The objective of this analysis is to represent the team DM process. In the M-OODA model proposed by Rousseau & Breton (2003), such decision is available after the third module. The AI module represents the execution of the selected set of actions resulting from the first three modules. Then, the modeling of this module may be outside of the scope of this document. Furthermore, in many situations, a complete new team is responsible for this module. As a result, the representation of the team dimension within the M-OODA model will be kept for only the first three ones. Furthermore, for a simplicity matter, the iterations included in the M-OODA model are not explained in this document. Only the interactions within the modules between the team members and the role of the TFE are detailed.

Obviously, the number of members within a team can vary from one situation to another. However, in order to demonstrate the modelling effort and make comparison between the different team models, we keep the number of team members constant. In each module included in the different team models, the processing is either under the responsibility of one agent (team dimension absent) or three agents (team dimension present).

3. The Modelling Demonstration

3.1 A Team DM Model for the Autocratic Type

An autocratic type can be adopted in highly complex and time-pressed situations. A characteristic of this type is that the final decision is the responsibility of a team leader. The role of team members is to provide information reports to this team leader in order to support him in the selection of the best decision. His selection leads to the implementation of the set of actions.

There are two main benefits related to the adoption of this particular type. First, it brings together the required expertises in order to process different sources of information found the environment. This processing leads to the constitution of the information reports sent to the team leader. Second, by letting the responsibility of the final decision to a single expert, the time to take it can be considerably reduced. Debates over the selection of the final decision occurring within a team can be very time-consuming. To demonstrate the modelling of an autocratic team decision-making type, let's take a fictive situation characterized as follow:

<u>Situation Description:</u>

- The environment is characterized by different types of data requiring specific and specialized sensors to be processed. In this situation, three different sensors are used to cover different sources of data.
- Each sensor produces a specific representation of the data gathered.
- Different expertises are required to interpret the representations produced by the sensors.
- Experts develop an interpretation of the situation based on the information considered in their analysis. The information is provided by a sensor covering a fraction of the whole picture. Then, it results in a partial interpretation of the situation since it is based on partial information.
- The interpretation of each expert must be sent, at the same moment, to a team leader in charge of the final decision.
- The synchronization of the report sending process is important since a non-significant piece of information in one report could become crucial when put in conjunction with another included in a different report produced by a different expert.
- The team leader has the authority of distributing the workload among team members (human experts or sensors) if it is judged necessary.

Figure 9 presents the modelling of this specific situation with the inclusion of appropriate TFE in order to show the team dimension. As mentioned above, the execution of the AI module is kept at the individual level proposed in the M-OODA loop model of Rousseau & Breton (in preparation).

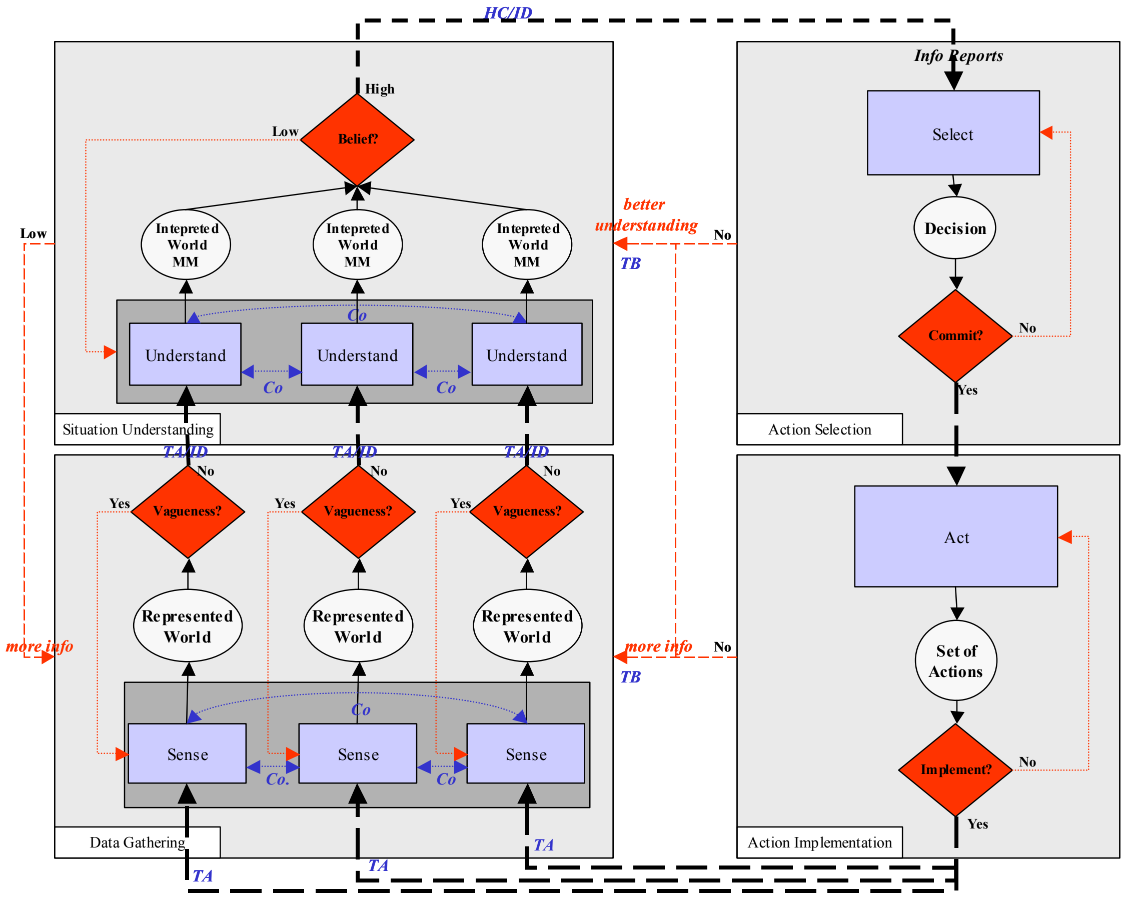

Figure 9. *The Autocratic Team DM model.*

Module Description: the DG module

This situation is marked by important time constraints, and different sources of data. To cope with the diversity of data, three different sensors are used. The role of these sensors is to produce world representations based on the data processed. To represent the work of sensors in the DG module, the BB-1 is used (see Figure 2, p. 7). In this BB, sensors are working in parallel without interacting or exchanging information. They all consider different sources of information. Sensors must be adequately allocated (TFE-TA) according to their properties and functions to the different sources of data available in the environment. In order to get an optimal coverage of all the available sources, the work of sensors must be coordinated (TFE-Co).

Each sensor produce a representation of the world based on the data processed. The quality of each world representation is controlled by a specific criteria-based component. This component allows an iteration process from which the quality of the representation is improved. In the DG module, the quality is based on the level of vagueness. Breton, Rousseau & Price, (1999) have associated this type of uncertainty with the Observe module of the OODA loop. In the DG module, iterations are made until the clearness of the picture reaches an acceptable level. Missing or ambiguous data challenge the picture clearness. However, since the situation is time-pressed, a trade-off between the quality and the time required to reach it is necessary. The best representation must be produced in an acceptable period of time. Since the sensors are controlled by a different component, the level of quality and the time taken to produce the representation may be variable from one sensor to another.

<u>Module Description: the SU module</u>

In this situation, three sensors are producing three different sources of information (world representation). To understand these sources, three different experts are required. Here, two TFE are interacting together. First, it is essential that an expert being allocated to a task, that is the processing of a specific source of information, that correspond to his expertise (TFE-TA). Second, it is important that a given source of information being distributed to the appropriate expert (TFE-ID). Each expert has the responsibility of interpreting its allocated information source. To represent the team execution of the SU module, the BB-2 is used (see Figure 3, p. 7). In this module, efforts of team members in the understanding process must be coordinated (TFE-Co). It may be very important to eliminate duplication in the coverage of the information (two or more team members covering the same information) or to ensure that no information is left uncovered. This TFE is particularly important since they all covering different parts of the environment from different backgrounds and expertises. According to the information considered, every team member possesses an interpretation of the situation that can differ considerably. It may be much more important and challenging to coordinate actions from these team members in comparison with the coordination of action of team members having the same expertise.

Note that the TFE-HC element is not included in the SU module. The presence of important time constraints may prevent the sharing of point of views, ideas, thoughts, or more simply, information. Breton et al. (1999) have proposed the level of belief as being the type of uncertainty for the Orient module of the OODA loop. The picture provided by the DG module may be clear, but doubts may be related to its plausibility. Then, iterations may be required to improve its level of belief. Here, again, since the situation is marked by time constraints, the level of belief must reach an acceptable state in the available period of time. In order to raise the level of homogeneity in the quality of the interpretation built by each expert, these interpretations are controlled by a unique control component. It also ensures that these different interpretations can be delivered at the same moment to the team leader. This can be critical since the level of importance of a piece of information included in a given report may significantly increases when put in conjunction with another piece of information included in another report. However, the time constraints must be considered in this control component.

Rather than linking the team members together, the TFE-HC element links the different team members with the leader. As it can be seen in Figure 9, TFE-HC is important in the process of providing information reports to the team leaders. For instance, non-verbal language and emotions can traduce the importance of the information. However, not only the way the information is provided to the team leader is important, but also the content. Then, TFE-ID also plays a role in the link between both the SU and AS modules.

<u>Module Description: the AS module</u>

In our fictive situation, the time and complexity of the environment are critical issues. In order to cope with the complexity, different sensors and experts are required. To cope with the time constraints, they work in parallel each addressing a specific part of the environment. In the autocratic mode favoured in this situation, the final decision is the responsibility of a team leader that is also seen as an expert of the domain. The team leader must select the best alternative for the situation from both the information reports provided by his team and in his expertise and knowledge. Depending on the importance of time constraints in the situation, a team leader may shift from the autocratic type to a more consultative mode in which he can share the problem with the other team members and gathers ideas and suggestions before making the solution alone. The consultative type is part of Vroom & Yetton (1973) classification. In our example, there is no TFE involve in the execution of the AS module. In fact, the team dimension is absent. A single individual is responsible for the execution of this module. The basic module is used to represent this module. Breton et al. (1999) defined the level of commitment as being the type of uncertainty related to the Decide module of the OODA loop. Thus, the picture provided by the DG module may be clear, its plausibility evaluated in the SU module may reach an acceptable level, but doubts and uncertainty may characterize the question of commitment. Then, iterations are made, during the period of time available, to clarify this question.

In case of overload for some of the team members or sensors or to request more information or better understanding, a task balancing (TFE-TB) process is performed. This process can be under this responsibility of the team leader. The TFE-TB element plays a major in the team organization in order to cope with the complexity of the situation and the important time constraints. TB allows a readjustment process in which part of some tasks can be reassigned to other less loaded or more appropriate team members or agents.

3.2 A Team DM Model for the Democratic Type

With an increase of time pressure but a decrease in the need of different skills (see Figure 8), a democratic mode may be more appropriate. In these situations, it may not be necessary to own specific expertises or skills to process the data available in the environment. The workload related to the data processing may not also represent a problem for the human information processing capacity. The need for a team may be more justified by the presence of important time constraints that can prevent team members to exchange ideas, opinions or information and build satisfying interpretations of the situation. In that sense, their interpretations, based solely on their knowledge and background can be highly subject to individual biases. One solution to overcome the problem of biases, is to use an election process to vote on a final decision that represents the majority of the team members' opinion. Every team member must vote on a potential solution in respect of his understanding of the situation. The following fictive situation is taken to demonstrate the modelling of the democratic team DM type:

<u>Situation Description:</u>

- The data gathered from the environment does not need specific expertises of skills to be processed. Consequently, a unique and generic sensor processes the data and builds a unique world representation that is made available to all team members.
- Team members develop an interpretation on this unique source of information. Then, they develop a mental model on the whole situation. Even if no specific expertise is required, their interpretation is obviously influenced by their background, past experiences and knowledge.
- The importance of the time constraints prevents any form of opinions or ideas exchange between the team members.

- Based on their respective interpretation of the whole situation, the team members must select or vote for the best course of actions.
- The selected course of actions (decision) represents the one that has received the most votes from the team members.

Figure 10 presents the modelling of this specific situation with the inclusion of appropriate TFE in order to show the team dimension.

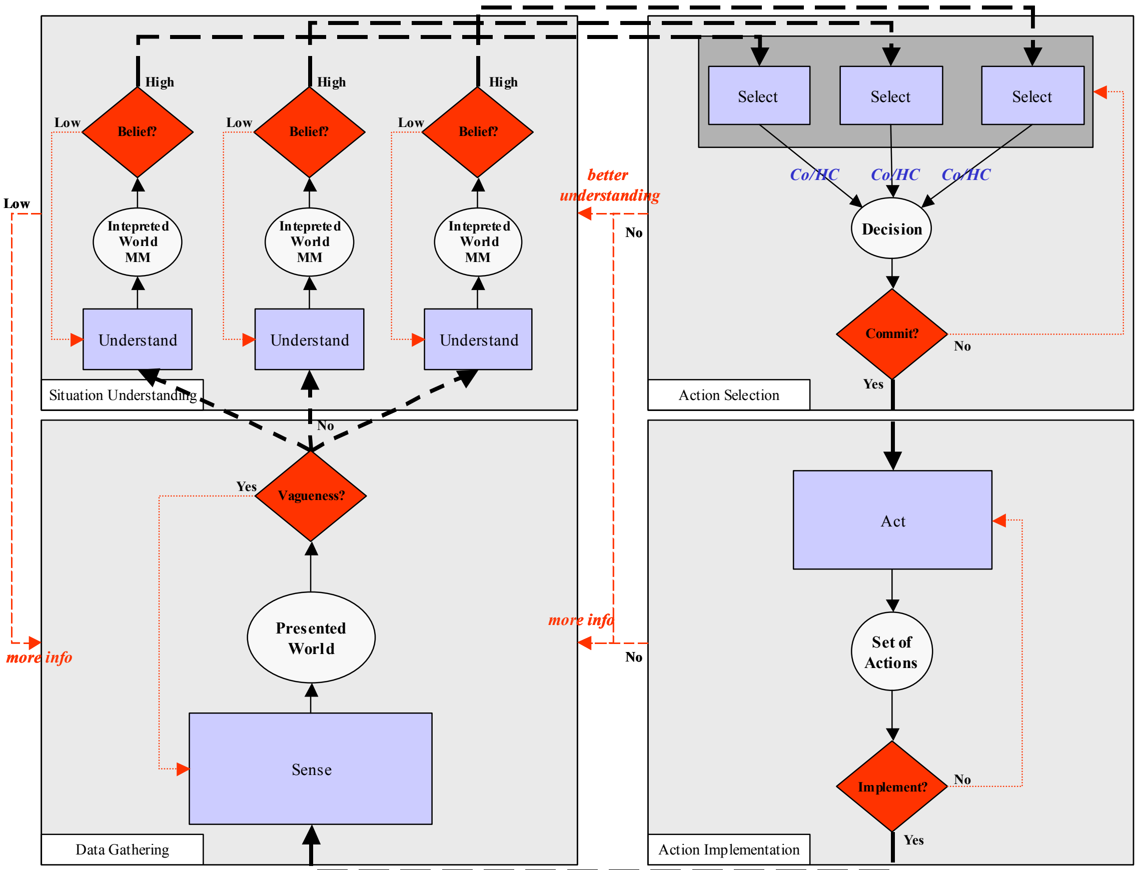

Figure 10. *The Democratic Team DM model.*

<u>Module Description: the DG module</u>

In the DG module, the team dimension is absent. In fact, the basic module is used to represent the unique and generic sensing process that produces the world representation. This unique world representation is made available to all team members for further processing such as interpretation. Because of the time constraints, it may be possible that the representation is distributed to team members even if it does not reach a certain level of quality in terms of vagueness.

<u>Module Description: the SU module</u>

In this situation, all team members have access to the same source of information. From that source, they build their own interpretation of the situation based on their background and knowledge. To represent the SU module, the best BB is the 1a (see Figure 2, p. 7). In this BB, a general and unique source of information is fed into three different understanding processes working in parallel.

With a general set of skills, all team members are adequately equipped to process the represented world produced by the DG module. Each team member has access to all the information available. However, it does not necessarily mean that they process the maximum of the information. Depending of the time they require for the processing of the information, the time constraint may affect more some team members than others.

In an autocratic mode (see Figure 9), the TFE-Co is critical to coordinate the actions of different experts processing different parts of the environment. In the democratic type, such coordination is not necessary. All team members cover all the information. Then, problems such as coverage duplication or lack of coverage of parts of the information are not relevant in this situation.

To cope with the time pressure, any form of opinions, ideas and information exchange is possible between team members. As it can be seen Figure 10, the team members are working in parallel on the same source of information. It results in three interpretations of the same information that may slightly differ according to team members' differentiations (historical background, personality, interests, pre-conceptions, etc). The quality of each interpretation or mental model is controlled by a specific criteria-based component. Based on the level of belief in the situation, each team member improves the quality of the interpretation from an iteration process. However, since the situation is time-pressed, a trade-off between the quality and the time required to reach it is necessary. Then, each team member must develop a trusted and believed interpretation of the situation in respect of the time constraint. Since they all have different background, knowledge and criteria, the level of quality and the time taken to produce the interpretation should be variable from one team member to another. These differences between team members may explain for differences in interpretation of the same information and then, differences in the voted decision.

These individuals are forming a team in a sense that they share the goal of understanding the situation and find the best alternative as possible. However, to cope with the time constraints characterizing the situation, they are not interacting together in this module. Consequently, no TFE is required in the SU module. The team dimension is not present. Team members are ready to take their vote as soon as their level of belief related to their interpretation reaches an acceptable level.

Module Description: the AS module

In the AS module, team members are joining their efforts in order to produce a single result. This situation can be represented by the BB-3 (see Figure 4, p. 8). In the AS module, after developing a respective mental model of the situation in the SU module, each team member vote or select the best course of actions based solely on their judgement. The final decision is simply the majority of the vote taken by the team members. Here again, to cope with the time constraints, the team members do not deliberate over the action selection. However, a certain level of coordination (TFE-Co) and communication (TFE-HC) can be required in the elective process.

Interestingly, since they work in parallel without interacting with others, it is plausible to assume a strong coupling between the SU and AS modules. It is possible that the result of the SU module, the interpreted world, already contains a decision.

While, in the democratic type of team DM, the decision can be seen as the result of a team effort, in reality, it is the result of a group of persons working in parallel. Consequently, the team dimension may not be important in this specific type of team DM.

3.3 A Team DM Model for the Deliberative Type

As the importance of time pressure and the need for different skills in the situation decreases, a deliberative mode can be adopted (see Figure 8). This mode is very beneficial since it allows the selection of the optimal decision. Then, this type can be adopted when the conditions are favourable (no time constraint, no specific skills required). In this type, all team members have access to the same information and they have all the time available for the deliberation process. The goal of this deliberation process is a consensus over an understanding and since the time factor is not an issue, the decision process may end with the selection of the best possible solution. The best example for this situation is described with the decision taken by a jury. To demonstrate the modelling of the deliberative team decision-making type, let's take a fictive situation characterized as follow:

- The data gathered from the environment does not need specific expertises or skills to be processed. Consequently, a unique and generic sensor processes the data and builds a unique world representation that is made available to all team members.
- Team members develop an interpretation on this unique source of information. Then, they develop a mental model on the whole situation. Even if no specific expertise is required, their interpretation is obviously based on their subjective judgement.
- Since, there is no time constraints in the situation, team members are encouraged to share information, opinions or ideas on the interpretation of the situation.
- The fusion of all team members' interpretations leads to a unique shared interpretation from which a decision is taken. All team members must agree on the interpretation, whatever the time required to reach that agreement.
- After agreeing on the interpretation the situation, the team members must agree on the selection of a course of action.

Figure 11 presents the modelling of this specific situation with the inclusion of appropriate TFE in order to show the team dimension.

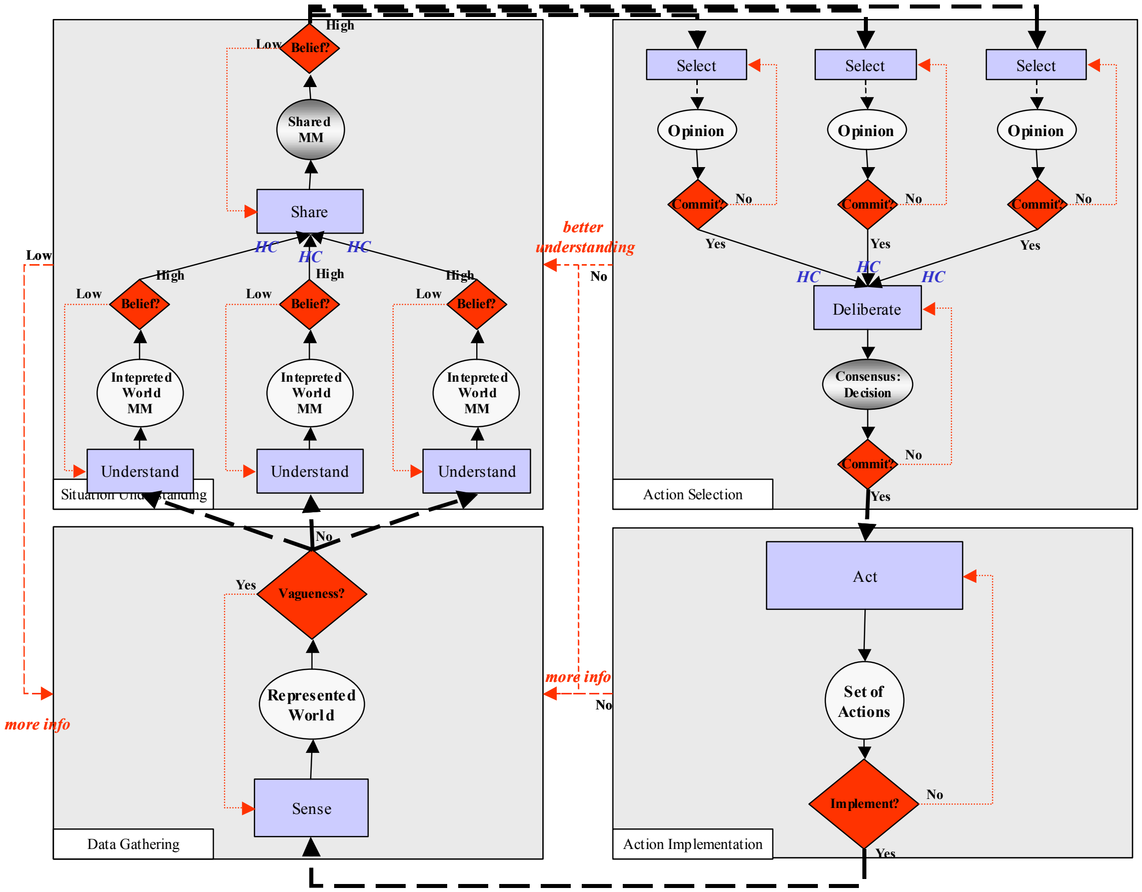

***Figure 11.** The Deliberative Team DM model.*

<u>Module Description: the DG module</u>

Similarly to the democratic type described above, the team dimension is absent of the DG module in the deliberative mode. Here again, the basic module is used to represent the unique and generic sensing process that produces the general world representation. In this situation, the time is not an issue. Then, the world representation is made available to all team members only when it reaches a certain level of quality based on the level of vagueness.

<u>Module Description: the SU module</u>

To represent the activities included in the SU module, a conjunction of the BB-1a (see Figure 2, p. 7) and the basic module can be used. The SU module can be divided in two distinct layers leading to the argument that this module could be split in two different ones. A first layer (BB-1a) represents the individual interpretation of the situation by each team member and the second layer (basic module) concerns the sharing process of all different interpretations into a general and shared one. To represent the activities included in the situation-understanding subtask, we keep these two layers together in one module.

In the first layer, all team members have access to the same source of information. From that source, they build their own interpretation of the situation based on their subjective judgement. However, contrarily to the democratic type, time is not an issue in the deliberative one. In fact, after reaching an optimal level of quality (in terms of uncertainty) in their own interpretation of the situation, team members join their effort in a sharing process in order to build a shared and common interpretation (second layer). Here again, this shared interpretation must reach an optimal level of quality whatever the time required to reach it. Since all team members have access to all the information made available by the DG module, the inclusion of the TFE-Co is not relevant.

The main distinction between the democratic and deliberative type lays in the presence of time constraints in the first one. In the deliberative type, since time is not an issue, team members can share information, ideas, opinions or thoughts on the situation. It results in a team shared mental model that is built from the different team member's interpretations. This team mental model may be less subject to individual biases and may be more complete and accurate. The HC element influences the development of a shared mental model. Note that since they all considering the same source of information, their actions related to the understanding process do not have to be coordinated. Notions such as leadership, orientation, feedback and initiative may play a major role in the sharing awareness process.

Module Description: the AS module

In the AS module, a conjunction of the BB-1 and the basic module is also used. In a first layer (BB-1), every team members built in parallel an opinion, based on the shared interpretation built in the SU module. In the second layer represented by the basic module, team members are debating over potential courses of actions in order to reach a consensus. Since, the objective of the AS module is different than the one in the SU, it can be seen as a different process than the one included in the SU module. In the SU module, the consensus is over the interpretation of the situation. In the AS one, it is related to the selection of the optimal decision from a set of alternatives. Here again, HC is a critical element in the sharing process of the different opinions. Uncertainty related to the capacity of commitment of the selected set of actions may cause number of iterations in this module. Since time is not an issue, a course of actions is selected when it represents any doubt or uncertainty in terms of commitment. Note that the TFE-Co is not included since they are considering the same shared interpretation.

In this specific situation, a team is formed in order to reach an optimal decision and to reduce as much as possible individuals biases. Consequently, the only TFE required is HC. Team members are doing the same tasks that do not necessarily require specific skills and expertise. They also not constrained by deadlines.

3.4 A Team DM Model for the Cooperative Type

The last example of our modelling approach is made with a situation characterized with the absence of time constraints, but the need for different skills to cope with different sources of information. In this situation, the reason for having a team is to gather different experts required by the presence of specific sources of information. However, since there is no time constraint, all team members can be involved in the comprehension of the problem, the generation of alternatives and the selection of the solution. Then, a cooperative mode can be adopted. The fictive situation used to demonstrate the modelling approach is characterized as follow:

- The environment is characterized by different types of data requiring specific and specialized sensors to be processed. In this situation, three different sensors are used to cover different sources of data.
- Each sensor produces a specific representation of the data gathered. Different expertises are required to interpret the representations produced by the sensors.
- The information is provided by a sensor covering a fraction of the whole picture. Experts develop an interpretation of the situation based on this partial information. However, each expert can have access to other sources of information if desired.
- Since, there is no time constraints in the situation, team members are encouraged to share information, opinions or ideas on the interpretation of the situation.
- The fusion of all team members' interpretations leads to a unique shared interpretation from which a decision is taken. All team members must agree on the interpretation, whatever the time required to reach that agreement.
- After agreeing on the interpretation the situation, the team members must agree on the selection of a course of action.

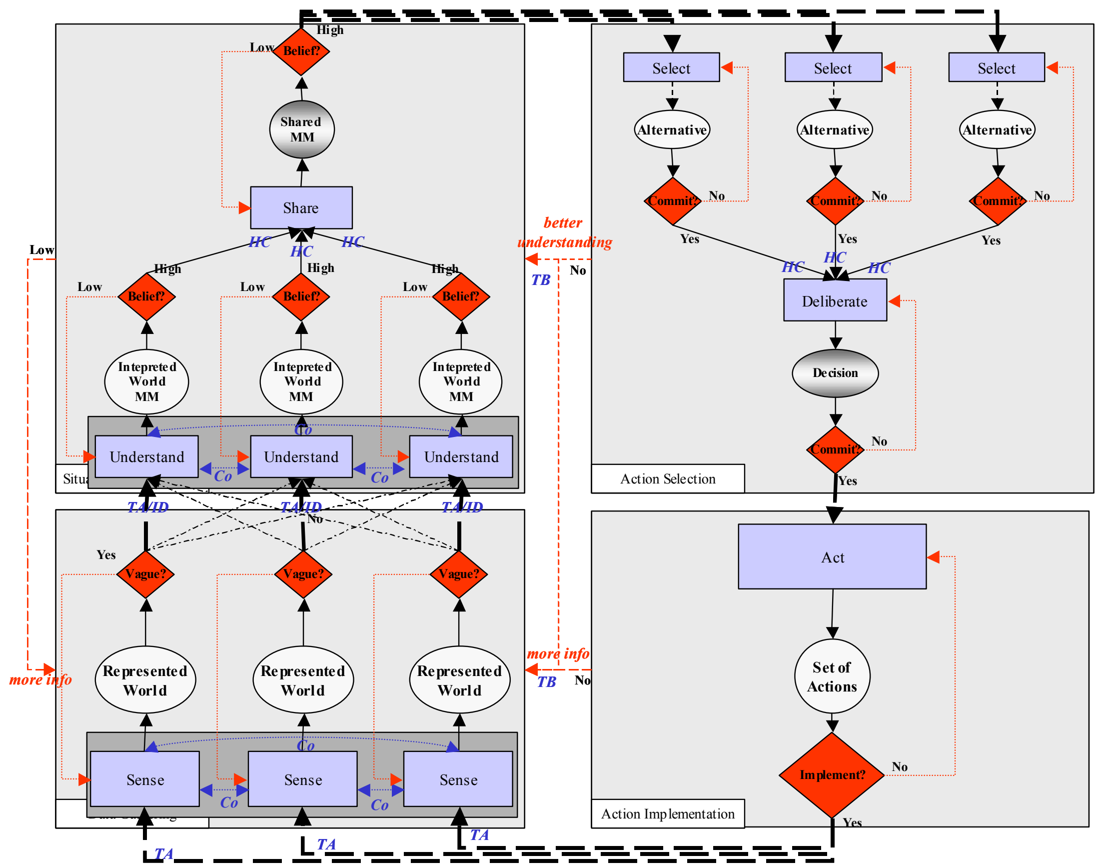

***Figure 12.** The Cooperative Team DM model.*

Module Description: the DG module

The description of this module is similar to the one offered in the autocratic type. Here again, to represent the sensors' work, the BB-1 is used (see Figure 2, p. 7). As in the autocratic type, the TFE-Co is important to coordinate the sensors working in parallel. Also, they have to be allocated to the part of the environment matching the properties and functions (TFE-TA).

The difference with the autocratic type is in the absence of time constraints in the cooperative one. This characteristic has important incidence on the quality of the representation of the world produced. The iteration process leading to the improvement of the represented world stops only when the quality of this state reaches the optimal level, the one that is the most certain (no vagueness). Similarly to the autocratic type, since the sensors are controlled by a different component, the time taken to produce the optimal representation may be variable from one sensor to another.

Module Description: the SU module

The description of this module is similar to the one proposed above for the deliberative type. However, there are some slight differences between both modules. First, in the cooperative type, each team members may have access, if desired to other information sources distributed to other team members. Then, a conjunction of the BB-1b (see Figure 2, p. 7) and the basic module can be used. This particularity could affect the quality of the coordination of the efforts. It could happen that one expert is more concerned by information originally distributed to another expert and then neglecting his allocated source. This could result in a problem of environment coverage. The TFE-Co becomes an important team aspect of this module. Moreover, it raises the importance of allocating accordingly the task to the different experts in order to reduce potential confusion or overlapping (TFE-TA). It raises also the need to distribute adequately the primary information to the appropriate expert (TFE-ID).

The second difference lays in the fact that instead of interpreting the same information source as in the deliberative type, the three experts involved in the cooperative one have their own information source. These sources (world representation) are produced by three different sensors. Then, these sources must be adequately allocated to the appropriate experts (TFE-ID). Each expert has the responsibility of interpreting its allocated information source.

As in the SU module described in the deliberative type, the TFE-HC plays a major role in the sharing process of all experts' interpretations. It is particularly important since all team members own a different expertise. Consequently, the communication process may be challenging if no rules of communication protocols are defined. Here again, the absence of time constraints allows the team members to develop an optimal shared interpretation of the situation.

Module Description: the AS module

The AS module is exactly the same as the one used in the deliberative type. A conjunction of the BB-1 and the basic module is represent the AS module in the cooperative type. No further details are required to describe this module except that the absence of time constraints allows the selection of the optimal course of action. Note that the TFE-HC may be more important in the cooperative type since the different expertises of the team members. In case of overload or answer request for more information or better understanding of the information, a task balancing process (TFE-TB) is possible. Note that the TFE-Co is not included since they are considering the same shared interpretation.

4. Discussion

It is a common and successful strategy to base the design of DSS and development of training programs on individual DM models when a single person performs this specific task. Common sense would dictate that this strategy should be extrapolated to the DSS design and training programs development for teams. However, for many reasons, the execution of the DM task by one person is fundamentally different to the one made by a team. Processes and elements such as communication, information exchange, shared situation assessment, and coordination can be critical in the team execution but not relevant for the individual one. As a result, individual DM models can be misleading and useless to support DSS design and training program development for teams. It raises the need for DM models addressing the team dimension. One problem facing the development of team DM models is the multiplicity and variability in the task execution with the conditions in the environments. According to these varying conditions, the team may perform the task differently. Without an appropriate approach, the development of various team DM models to represent each potential situation can be time and effort consuming. A task or domain oriented approach must be adopted. This technical report presents an approach to rapidly and easily build different team DM models based on conditions in which the task is performed. From these different models, the team dimension can be evaluated.

There are multiple reasons to justify the constitutions of teams. While some may be political, others are related to the conditions prevalent in the environment. In this technical report, we identify two general conditions: time pressure and environment complexity. Teams are required when the time available in the situation is shorter than the time required by one individual to perform the task. Teams are also required when the complexity of the information processed requires different skills and expertise owned by different experts.

In addition, conditions may change from one moment to another. It is essential that teams can adjust their operations regarding the influence of the conditions prevalent in the environment. It becomes critical that training programs address the importance of the team flexibility. It is also important that the DSS being compatible with the various team organizations. The reorganization may involve change in the team size, member proximity, task type, centralization of control, temporal distance and degree of cooperation (Huber, 1990). In that sense, adaptive intelligent interface must be designed to support the task execution in changing conditions and different organizations.

In order to define appropriate training programs and to design useful DSS for teams, the team dimension must be evaluated from 1) the different building blocks used to represent the team architectures or organizations and 2) the implication of the different TFE in these team organizations. For a given environment, like C^2, several team models may be required to represent the various conditions in which the DM task is executed. The analysis should be extended to the comparison between these models. This analysis should allow the development of training programs that prepare team members to switch from one mode of team DM to another. It should also provide valuable insights for the design of DSS that can adapt from one mode to another.

In summary, the analytical process should consider 1) the building blocks used to represent the team organizations and 2) the TFE involved within and between the modules.

4.1 The Comparison Between the Different Models in terms of the BB Used to Represent the Different Modules Execution

A first step in the analytical process is to compare the different team organizations from the BB included in the different models. Table 7 shows the different BB used to represent the different module executions in our team DM situations.

Table 7: The BB used to represent the modules architectures in the autocratic and cooperative types.

	Autocratic	Cooperative	Deliberative	Democratic
DG	BB-1	BB-1	Basic	Basic
SU	BB-2	BB-1b + Basic	BB-1a + Basic	BB-1a
AS	Basic	BB-1 + Basic	BB-1 + Basic	BB-3
AI	Not modeled	Not modeled	Not modeled	Not modeled

Note that development of training programs and DSS design should be based on a complete analytical process that involves the team DM models required to represent the different team organizations. The analytical process should be based on a complete evaluation of the benefits and costs of switching from one mode to another. Next, in order to provide an example of this analytical process, we compare the models representing the autocratic and cooperative types of team DM.

In both types, the DG module is represented with the same BB (BB-1). The activities performed in the DG modules are structured similarly in the autocratic and cooperative types. Agents are performing their tasks in parallel without communicating. In both situations, their efforts need to be coordinated in order to ensure an optimal level of environment coverage. Consequently, a team may switch from one type to another without interfering or changing the way they perform the DG activity.

The SU module is structurally different in the autocratic (BB-2) and cooperative (BB-1b + basic) types. A first distinction concerns the distribution of the information provided by the DG module. In the autocratic type, agents have access to one specific source of information based on their expertise. In the cooperative one, they are also responsible for the processing of their allocated source, but they also have access to other sources. Then, for the autocratic-to-cooperative switch, a means must be established within the team to make possible the access of other agents' sources of information. For the cooperative-to-autocratic switch, a filtering process may be required to redistribute properly the specific information to the appropriate expert.

There is another major distinction in both SU modules of each type. In the autocratic type, the understanding process of each agent is controlled by a single general criteria-based control component. In the cooperative type, each agent has its own control component. This distinction represents a major concern when the team switches from one type to another since it may change drastically the result of the understanding process. For the autocratic-to-cooperative type, means must be put in place in order to help the agent to define their own criteria-based control component. For the cooperative-to-autocratic switch, the team must define a unified control component. The team leader may play a major role in this situation.

There is a third important distinction in the SU modules for each type. In the autocratic type, the sending of information reports to a team leader is synchronized. However, these different reports are not fused. In the cooperative type, these different information report based on the understanding process of each agent are fused in a single one and then, sent to the next module. This distinction produces an asymmetrical cost in the switching process. In the autocratic-to-cooperative type direction, the cost may be important since the fusion process must be introduced. In the other direction, it is simply removed from the task in the SU module. However, the team leader may have to perform, mentally, this fusion process before taking any decision in the AS module.

AS module is also structurally different in both team DM types (see Table 8). In the autocratic one, there is no team dimension in this module. Team leader is accountable for the decision. In the cooperative type, agents in charge of the other modules are also involved in the AS module. Consequently, the cost to switch from an autocratic type to a cooperative one can be important since it requires the establishment of communication means between agents involved in the module execution as well as the introduction of a sharing and deliberation process. The cost to switch from a cooperative type to the autocratic one is lesser since it concerns mainly the removal of the team dimension in the module.

4.2 The Identification of the TFE in each Team DM Models

A next step in the analytical process is to identify the TFE included in the different team DM models. Table 8 shows the distribution of the TFE within the autocratic, cooperative, deliberative and democratic types of team DM. The Table shows, for each type, the number of times each TFE appears within (intra) or between (inter) modules in the model.

Table 8: The distribution of the TFE in the two types of team DM used in C^2 environment.

	Autocratic		Cooperative		Deliberative		Democratic	
	Intra	Inter	Intra	Inter	Intra	Inter	Intra	Inter
TA	0	2	0	2	0	0	0	0
TB	0	4	0	4	0	0	0	0
ID	0	2	0	1	0	0	0	0
Co	2	0	2	0	0	0	1	0
HC/TC	0	0	2	0	2	0	1	0
# TFE	2	8	4	7	2	0	2	0

Generally, it seems that the team dimension is much more important in the autocratic and cooperative types in comparison with the deliberative and democratic ones. Here again, the analytical process should involve all team DM types used in a given environment. For a matter of length and simplicity, we only show the comparison process between the TFE included in the autocratic and cooperative types of team DM. The identification and comparison of the TFE in these models suggest some hypothesis:

- It seems that the team dimension is equally present in both team DM types as shown by similar TFE distribution within and between modules. For both types, TA, TB, ID and Co elements seem to intervene almost equally. The main difference concerns the HC/TC element that is absent in the autocratic type. This can be explained with the importance of the time pressure that may prevent any kind of communication.
- The inclusion and distribution of the TFE suggest that the Co, TA and TB elements seem to play exactly the same role and intervene at the same moment between the modules. Consequently, the cost to switch from one type to another should be minimal for these TFE.
- A first distinction concerns the ID element. In the autocratic type, the ID element must connect the SU and AS module in order to ensure that the information transmitted by the agents in charge of the SU module is understandable by the agent responsible of the AS one. Such condition may not important in the cooperative mode since the agent in the SU module are also involved in the AS one. As a result, problem such as information misinterpretation may be considerably reduced. The cost raised by the switch from one type to another is asymmetrical. In the cooperative-to-autocratic direction, the activities related to the ID element that intervene between the SU and AS modules must planned. The cost in the team performance may be important if no means are available or the transition is difficult. The cost should be minimal when the switch is in the other direction (autocratic-to-cooperative). The ID elements and its activities should no longer be an issue.
- Another distinction concerns the HC/TC element. In the autocratic type, communication activities are removed among team members in order to cope with the importance of the time constraints. These HC/TC elements should play a major role in the SU and AS module in the cooperative type. Consequently, the switch between the DM type should be much more difficult and costly in the autocratic-to-cooperative direction than the other one. To switch from an autocratic to a cooperative type, communication means should be planned and established.

Such comparison process related to the TFE may not be sufficient to determine training and programs requirements. However, it may support the identification of hypothesis that can be validated from appropriate experimental activities. As mentioned above, the development of training programs and design of DSS should be based on a complete analytical process between all the different team DM types used in a given environment. For instance, if the autocratic, cooperative and democratic types of team DM are frequently used in a given environment, the analytical process should include a complete set of comparisons between these three types.

4.2.1 The Identification of Organizational, Training and Design Requirements from the Modelling Approach

The example illustrated above shows the analytical capabilities associated with the modelling approach. From Table 7 and 8, one may identify the TFE important in each type used by a team in different environments and conditions as well as the module architectures required to represent the task execution. It can lead to the identification of requirements that should influence the team organization, the development of training programs and the design of DSS. Table 9 shows example of such requirements based on the analysis shown above.

Table 9: Examples of potential Organizational, Training and Design requirements related to the switching activity between the autocratic and cooperative team DM types.

	Switch from an autocratic to a cooperative type	Switch from a cooperative to an autocratic type
Organizational requirements	The organization must permit the distribution of all different sources of information to all experts The organization must allow the introduction of a fusion process in the DG module The organization must be flexible enough to allow all agents to be involved in the decision process in the As module	The organization must permit the filtering of information The organization must identify a single criteria-based control component in the DG module The organization must identify a team leader
Training requirements	Team members must have a minimal expertise to process all the complementary sources information made available to them in the DG module Agents must be trained to build their own criteria-based control Team must be trained to share and fuse the information Team must be trained to deliberate over a potential decision	Agents must be trained to perform the understanding process in the DG module with a single and general criteria-based control component Team must be trained to perform their task in parallel without interaction
Design requirements	DSS must be designed in order to accept and represent properly all the different sources of information (primary and secondary) DSS must support the communication activities DSS must support the information fusion activity	DSS must be able to filter the appropriate information source in display it to a specific experts DSS must provide information on the single criteria-based control component of the DG module

4.3 The Relationship between the Modelling Approach and other Cognitive Task/Work Analysis Techniques

Task analysis techniques such as Cognitive Task Analysis (CTA) and Cognitive Work Analysis (CWA) are used to provide an understanding of a task execution, which in turn can lead to the identification of requirements for new training programs and systems designs. While these techniques seem appropriate to represent individual performance, they seem useless to represent the team dimension in a task execution. Baker, Salas and Cannon-Bowers (1998) raise doubts about the adaptations of job analysis methodologies, used as a primary strategy for conducting team task analysis, as an adequate approach to analyzing teams. There is still a need for appropriate methodologies for team analysis.

The modelling approach presented in this technical report is certainly not a CTA/CWA per se. However, coupled with an appropriate task analysis technique, it could cover the missing parts and then provides insights on the team dimension. Figure 13 presents a typical analytical process for individual task performance. The upper part of the figure (blue boxes) shows typical analysis from which new systems arise and training programs are implemented. The lower part (pink boxes) shows the addition of the team modelling that brings a new alternative that is organizational changes.

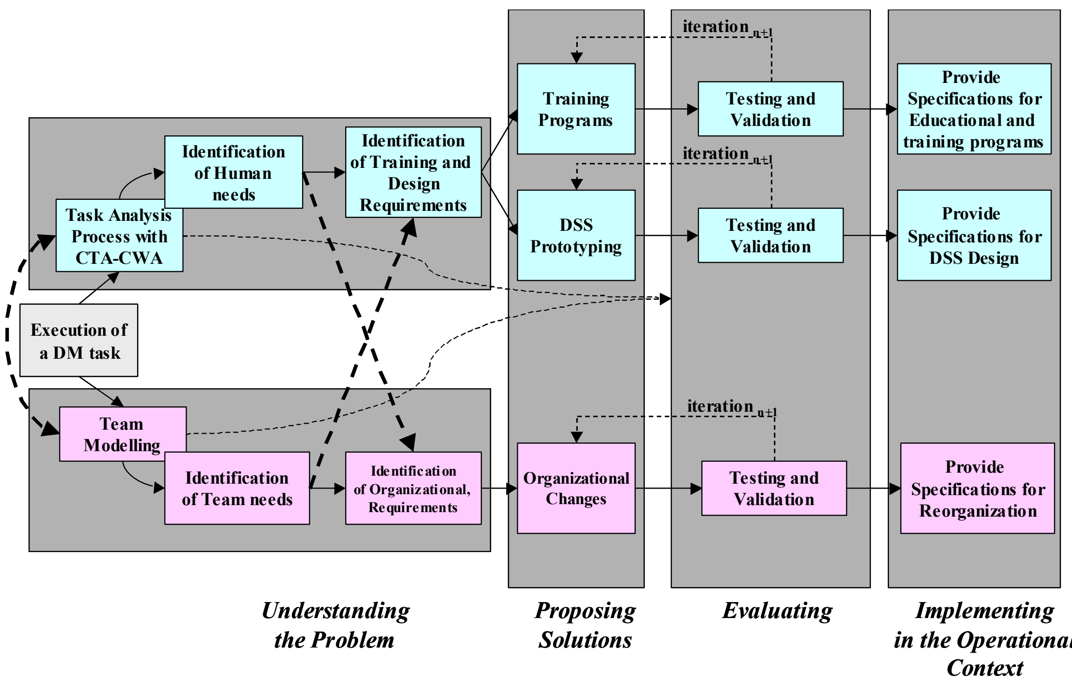

Figure 13. *The Analytical Process of task performance.*

In the first phase of the process (Understanding the Problem), the team modelling is based on the result of the task analysis process. It provides a description (flow chart type) of the connections and interactions between the processes or functions that lead to the task execution. In this report, instead of using the result of an analytical task, we have demonstrated the team modelling capabilities with the OODA loop model that identify the four major processes included in a DM task. The task analysis and modelling efforts lead to the identification of human and team needs. While the identification of training and design requirements is mostly based on the human needs, the team ones also influences these requirements. This mutual influence is also true for the identification of the organizational changes requirements.

The identification of these requirements based both on human and team needs lead to proposition for potential solutions (phase two: Proposing Solutions). It is followed with phase three (Evaluating). The validation process should be done from a human or team performance and an operational perspective. For instance, it may be possible that a potential solutions being adequate from a team performance perspective (improving significantly the team performance) but inadequate from an operational one (not possible to implement in the operational context). Numerous iterations between phases two and three are possible based on the time available to propose and evaluate new alternatives and resources (personal and money) available. The goal with each iteration is to improve previous solutions or propose new ones. Note that the testing and validation processes are influenced by the results task analysis and team modelling efforts as shown by the doted arrows between phase one and phase three. When the time to evaluate is expired, resources are no longer available or the proposed solutions reach an adequate level of quality, specifications for solutions implementation are defined (phase four: Implementing the Operational Context).

The phases included in the analytical process shown in Figure 13 are presented sequentially, but one may assume numerous iterations between them. Further, the result of the CTA/CWA and the team modelling processes may have a direct influence on the way the proposed solutions are tested and validated (shown by the doted arrows). Otherwise, the evaluation process can be reduced at simple usability testing. Note that this analytical process starts with the identification of problems. However, it may also starts with the validation of new technology. In that specific situation, the modelling of the team execution may support the testing and validation process of these new technologies by identifying the TFE critical. It can also support the cost and benefits of these technologies in terms of team interaction and task architectures. For instance, a new system may ease the interaction between team members (benefits) or ask for too drastic changes in the task execution (costs).

5. Conclusion

The execution of a given task might be different if the task is executed individually or within a team. Even within a given team, the variability in the task execution might also be important. This variability factor raises two different problems. First, the identification of requirements for training programs and DSS designs cannot be based on models representing the individual execution. There is a need for models representing the team execution. Second, to represent the multiplicity of task executions performed in different contexts and situations, many team models should be necessary. The modelling process should then be time and effort consuming. The modelling approach proposed in this technical report can address these two problems by offering guidelines and principles to rapidly develop different team models that represent the different team execution in function of the conditions in the task environment.

For two main reasons, we chose to show the modelling capabilities with a DM task. First, there is a need in literature for team DM models. In complex environments, teams are responsible for most of the DM tasks. Even if a single individual bears responsibility for the decisions, many participants contribute to the final product (Orasanu and Salas, 1993). Second, there is a consensus of the processes or functions included in a DM task in the literature. Most are including the ones summarize in the OODA loop model. However, the modelling approach can be used for every team execution involving cognitive processes like those included in the DM task. In some circumstances, the modelling approach should be based on the result of a CTA/CWA process that provides the architecture of the processes or functions included in a task execution. For instance, the modelling approach could be based on the Applied Cognitive Task Analysis (ACTA) proposed by Militello & Hutton (1998). One of the phases included in ACTA is to build a task diagram that provides an overview of the task and critical elements. Subject-matter experts are asked to decompose the task into subtasks in a flow chart format. From that diagram, the team modelling approach can be used to represent each subtask by a module with appropriate BB and TFE.

In future projects, the mapping of the team modelling approach with the ACTA technique should be tested. There is also a need to validate the TFE list. This list has been developed within the NATO TG-006, IST-019 mainly from literature reviews. A literature survey shows that the number of TFE required to make a team working properly is variable from one study to another. Moreover, the TFE are labelled differently across the different scientific papers. Other studies should be required to validate the importance of these six TFE and to verify if other elements are missing. Finally, more evidences should be required to validate the set of BB. Actually, the modelling approach includes nine different BB. It is important to verify the adequacy of the set to represent the majority of situations.

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List of symbols/abbreviations/acronyms/initialisms

ACTA	Applied Cognitive Task Analysis
AI	Action Implementation
AS	Action Selection
BB	Building Block
C	Criteria-Based Control
C^2	Command & Control
Co	Coordination
CTA	Cognitive Task Analysis
CWA	Cognitive Work Analysis
DG	Data Gathering
DM	Decision-Making
DND	Department of National Defence
DSS	Decision Support Systems
EL	External Feedback Loop
G	Goal
HC	Human Communication
HIP	Human Information Processing
I	Input
ID	Information Distribution
IL	Internal Feedback Loop
IST	Information System Technology
M-OODA	Modular-OODA
NATO	North Atlantic Treaty Organisation

O	Output
OODA	Observe-Orient-Decide-Act
P	Process
R-El	Request Loop
RPD	Recognition-Primed Decision
S	State
SU	Situation Understanding
TA	Task Allocation
TADMUS	Tactical Decision Making Under Stress
TB	Task Balancing
TC	Tool Communication
TDM	Team Decision-Making
T-El	Transfer Loop
TFE	Team Functioning Element
TG	Task Group

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This document proposes a modelling approach to address the need for the development of team models. The modelling approach is based on guidelines and principles in addition of sets of building blocks and team functioning elements. To demonstrate the modelling capabilities, four different team decision-making situations are defined. These situations vary in terms of time pressure and complexity of the information to be processed by the teams. According to these four different models produced with the modelling approach, there are differences in terms of building blocks used to represent module architectures between models and the team functioning elements essential for optimal team functioning. With the varying conditions in the environment, a team may switch from one type to another. The comparison between the different models allows the evaluation of the benefits-costs of switching between the different decision-making types. This benefits-costs evaluation is based on building blocks used and team functioning elements included in the models. While the modelling approach still requires more validation studies, it shows interesting potential to identify requirements for training programs development, decision support system design and organizational changes. (U)

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