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Constraint-based argumentation for decision support in the context of combat power management

H. Irandoust
A. Benaskeur
DRDC Valcartier

Defence R&D Canada – Valcartier
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Principal Author

H. Irandoust

Approved by

Éloi Bossé
Head/A Section

Approved for release by

C. Carrier
Chief Scientist

Abstract

This report describes an argumentation-based Decision Support System (DSS) that can assist the operator with target engagement within the Combat Power Management (CPM) process. It is shown how the information gathered and analyzed during the engageability assessment, a process based on the constraint satisfaction principle, can be exploited by an argumentation module. Using a dialectical model, the argumentation module enables the DSS to anticipate and respond to the operator's objections to its recommendations, and thus convince him of the soundness of its reasoning.

Résumé

Ce rapport décrit un système d'aide à la décision basé sur l'argumentation qui peut assister l'opérateur durant les opérations d'engagement de cibles, à l'intérieur du processus de Gestion de la puissance de combat. On y décrit la manière dont l'information recueillie et analysée durant l'évaluation de l'engageabilité, un processus basé sur le principe de la satisfaction de contraintes, peut être exploitée par un module d'argumentation. Utilisant un modèle dialectique, le module d'argumentation permet au système d'aide à la décision d'anticiper les objections de l'opérateur à ses recommandations et d'y répondre, le convaincant ainsi du bien-fondé de son raisonnement.

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Executive summary

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H. Irandoust, *A. Benaskeur*; DRDC Valcartier TR 2008 - 088; Defence R&D Canada – Valcartier; September 2008.

Background: Among other functionalities, shipboard Command & Control (C2) systems provide capabilities to allow operators to evaluate the threat level of the different objects within the Volume of Interest (VOI), and when deemed necessary, use the shipboard combat resources to respond to them. This defines the Combat Power Management (CPM) problem, which is commonly referred to as the Threat Evaluation & Weapon Assignment (TEWA). It provides a time and resource-constrained application that involves both human and software decision makers. This report focuses more particularly on the target engagement problem, which is one of the most challenging decision making tasks within the CPM process.

The proposed Decision Support System (DSS) assists the operator in making effective, error-free and timely decisions while reducing his cognitive workload. Yet, given the complexity of the problem he has to address, the high level of stress he is exposed to, and finally the fact that he knows that he will be held responsible for his decisions, the operator may discard the system's recommendation if he does not fully understand the underlying rationale. To overcome the operator's reluctance or lack of trust, the system has to convince him that its recommendation is based on sound reasoning. To do so, it needs to both retrieve the relevant knowledge structures and present them to the operator in a meaningful manner.

Principal results: In this report, we describe, on the one hand, the information processing capability of the DSS, which provides the operator with the best option among the feasible ones (and only those), and on the other hand, the persuasive capacity of the system, which not only presents arguments in favor of its recommendations, but is capable of anticipating and responding to the operator's possible objections to them. For the first purpose, we introduce and formalize the *engageability assessment* process, which provides the operator with the set of engagement opportunities given the whole set of operational constraints. For the second purpose, we describe the design of an argumentation module that organizes the results of the engageability assessment process into argument structures and presents them to the operator proactively and reactively.

Significance of results: The originality of this argumentation module is that it can address the specific problem of the operator's lack of confidence in the system's recommendation due to an *expectation failure*. The latter occurs when the DSS's results, based in this case on a constraint satisfaction principle, are different from what the operator had foreseen. Using a dialectical model of argumentation, the module anticipates the operator's objections and argues against them.

Future work: This methodology will be further investigated, within the ongoing project *Advisory Threat and Intent Assessment in Littoral Joint Context*. The aim of the project is to support decision makers for threat assessment during naval task force operations. In such operations, threat evaluation is the process of observing the behavior of potentially hostile entities to determine their goals, plans, intent, capability and opportunity for causing damage to protected assets. This process is conducted by human operators based on information provided mainly through a tactical picture. Given the very high complexity of naval task-force threat evaluation tasks, a decision support system that can enhance decision quality by reducing the risk of errors for operators, and gain their trust by providing insight into the system's rationale through argumentation is investigated.

Sommaire

Constraint-based argumentation for decision support in the context of combat power management

H. Irandoust, *A. Benaskeur* ; DRDC Valcartier TR 2008 - 088 ; Recherche et développement pour la défence Canada - Valcartier ; septembre 2008.

Contexte : Parmi d'autres fonctionnalités, le système de Commandement et Contrôle (C2) à bord du bateau offre des capacités qui permettent aux opérateurs d'évaluer le niveau de menace des différents objets à l'intérieur du volume d'intérêt, et lorsque jugé nécessaire, d'utiliser les ressources de combat du bateau pour y répondre. Cela définit le problème de la gestion des ressources de combat (CPM : Combat Power Management), également connu sous le nom d'évaluation de la menace & désignation des armes (TEWA : Threat Evaluation & Weapons Assignment). Il s'agit d'une application contrainte par le temps et les ressources, impliquant des décideurs humains et logiciels. Ce rapport met l'accent plus particulièrement sur le problème de l'engagement de cibles, l'une des tâches de prise de décision les plus exigeantes au sein du processus de CPM.

Le système d'aide à la décision proposé aide l'opérateur à prendre des décisions efficaces et sans erreur en temps opportun, tout en réduisant sa charge de travail. Or, étant donné la complexité du problème qu'il doit aborder, le niveau élevé de stress auquel il est exposé, et finalement le fait de savoir qu'il sera tenu responsable de ses décisions, l'opérateur peut rejeter la recommandation du système s'il ne saisit pas complètement le raisonnement sous-jacent. Pour surmonter l'hésitation ou la méfiance de l'opérateur, le système doit être en mesure de convaincre celui-ci que sa recommandation est basée sur un raisonnement solide. Pour ce faire, il doit extraire les structures de connaissances pertinentes et les présenter à l'opérateur d'une manière signifiante.

Résultats principaux : Dans ce rapport, on décrit, d'une part, la capacité de traitement d'information du système d'aide à la décision, lequel présente à l'opérateur la meilleure option parmi celles possibles (et seulement celles-ci), et d'autre part, la capacité persuasive du système, qui non seulement présente des arguments en faveur de ses recommandations, mais est capable d'anticiper et de répondre aux éventuelles objections que ces arguments pourraient susciter chez l'opérateur. Pour le premier point, on introduit et formalise le processus de l'évaluation d'engageabilité qui fournit à l'opérateur l'ensemble des options d'engagement, étant donné les contraintes opérationnelles. Pour le second point, on décrit le modèle conceptuel d'un module d'argumentation qui organise les résultats du processus de l'évaluation d'engageabilité en des structures argumentatives et les présente à l'opérateur de manière proactive et réactive.

Portée des résultats : L'originalité de ce module argumentatif tient au fait qu'il peut aborder le problème particulier de la méfiance de l'opérateur envers la recommandation du système en raison d'un *manquement aux attentes*. Ce phénomène se produit lorsque les

résultats du système d'aide à la décision, basés dans ce cas sur un principe de satisfaction de contraintes, sont différents de ceux que l'opérateur escomptait. Utilisant un modèle dialectique d'argumentation, le module anticipe les objections de l'opérateur et contre-argumente.

Recherches futures : Cette méthodologie sera étudiée plus en profondeur, dans le cadre du projet *Advisory Threat and Intent Assessment in Littoral Joint Context* actuellement en cours. L'objectif de ce projet est de soutenir les décideurs dans l'évaluation de la menace lors d'opérations navales menées par une force opérationnelle. Durant ces opérations, l'évaluation de la menace consiste à observer le comportement des entités potentiellement hostiles afin de déduire leurs buts, leurs plans, leurs intentions, leurs capacités et leurs possibilités de causer des dommages à des ressources protégées. Ce processus est effectué par des opérateurs humains à partir de l'information fournie principalement par l'image tactique de la situation. En raison de la très grande complexité des tâches d'évaluation de la menace, on étudie un système d'aide à la décision qui peut réduire les risques d'erreurs pour les opérateurs et gagner leur confiance en leur permettant de suivre la logique du système au moyen de l'argumentation.

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1 Introduction

Advances in threat technology, the increasing difficulty and diversity of open-ocean and littoral scenarios, and the volume and imperfect nature of data to be processed under time-critical conditions pose significant challenges for future shipboard Command & Control Systems (CCSs). Among other functionalities, the CCS provides capabilities to allow operators to evaluate the threat level of the different objects within the Volume of Interest (VOI), and when deemed necessary, use the shipboard combat resources to respond to them. This defines the Combat Power Management (CPM) problem, which is commonly referred to as the Threat Evaluation & Weapon Assignment (TEWA). It provides a time and resource-constrained application that involves both human and software decision makers. This report focuses more particularly on the target engagement problem, which is one of the most challenging decision making tasks within the CPM process.

Current operational systems generally provide little support for tactical decision making. The need for such support is all the more pressing given the current emphasis on littoral warfare, including asymmetrical threats, that results in reduced reaction time and the need to deal quickly and correctly with complex Rules Of Engagement (ROEs).

The role of a Decision Support System (DSS) is to assist the operator in making timely, error-free and effective decisions while reducing his cognitive workload. Yet, given the complexity of the problem he has to address, the high level of stress he is exposed to, and finally the fact that he knows that he will be held responsible for his decisions, the operator may discard the system's recommendation if he does not fully understand the underlying rationale, or if the recommendation is different from the solution he had foreseen. To overcome the operator's reluctance or lack of trust, the system has to be able to convince him that its recommendation is based on sound reasoning. To do so, it needs to both retrieve the relevant knowledge structures and present them to the operator in a meaningful manner.

In this report, we describe, on the one hand, the information processing capability of a DSS, which provides the operator with the best option among the feasible ones (and only those), and on the other hand, the persuasive capacity of the system, which not only presents arguments in favor of its recommendations, but is capable of anticipating and responding to the operator's possible objections to them. For the first purpose, we introduce and define the *engageability assessment* process which provides the operator with the set engagement opportunities given the whole set of operational constraints. For the second purpose, we describe the design of an argumentation module that organizes the results of the engageability assessment process into argument structures and presents them to the operator proactively and reactively. The originality of this argumentation module is that it can address the specific problem of the operator's lack of confidence in the system's recommendation due to an *expectation failure*. The latter occurs when the DSS's results, based in this case on a constraint satisfaction principle, are different from what the operator had foreseen. Using a dialectical model of argumentation, the module anticipates the operator's objections and argues against them.

The document is organized as follows:

In Chapter 2, the domain of Naval Command & Control (C2) is presented with a focus on the problem of Combat Power Management (CPM), which is one of the most important decision making issues in Naval C2. Within this framework, the concept of engageability assessment is introduced and formalized. Next, the relation between the engageability concept and the larger Constraint Satisfaction Problem (CSP) is described (Chapter 3). The user's expectation failure phenomenon is explained in terms of the number and the nature of constraints (soft or hard) considered by the user versus the system. Examples of CPM constraints are given to illustrate the problem. The idea of an argumentation-based DSS is then elaborated (Chapter 4). Related work in argumentation theory is discussed, including theoretical issues and application areas in Artificial Intelligence (AI). The use of dialectical argumentation for decision support is elaborated and an argument model with a dialectical component proposed. Finally, in Chapter 5, the design and the argumentative strategies of the constraint-based argumentation module are explained.

2 Naval Command & Control

Naval Command & Control (C2) is a very complex problem, and often this complexity rises from the multitude, the heterogeneity and the inter-relationships of the systems and resources involved. This is generally the case when simultaneous engagements involving heterogeneous sensor and/or weapon systems can take place (Figure 1)[1], and decisions are, for the most part, made by human operators. Decision support aids can help in overcoming the inherent complexity of such simultaneous engagements.

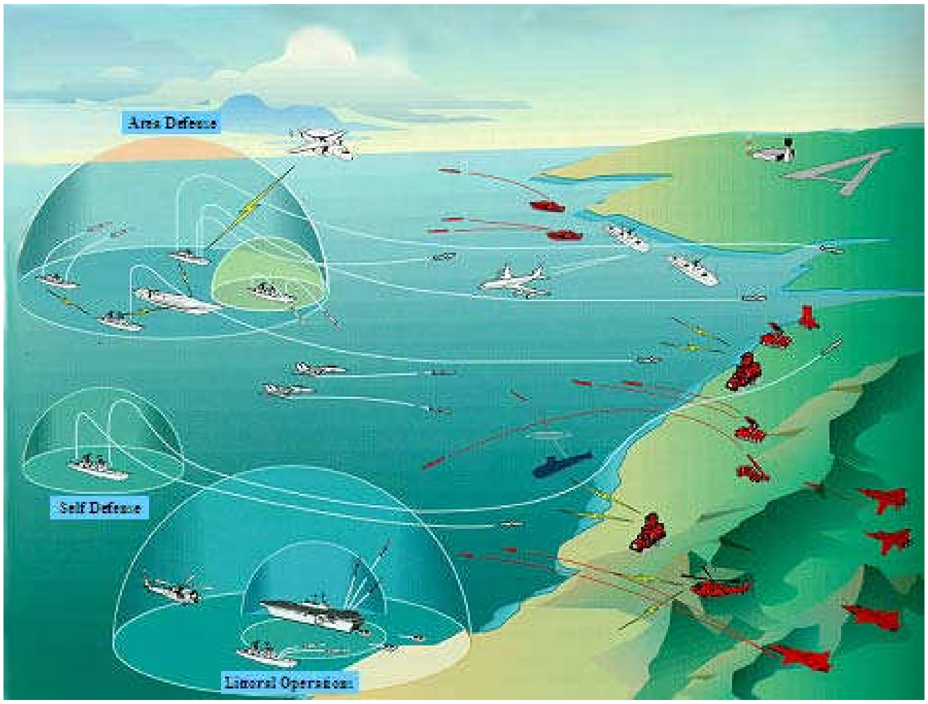

Figure 1: Complex engagement scenario

Naval C^2 can be decomposed into a set of generally accepted functions that must be executed within some reasonable delays to ensure mission success. A very high-level description of those functions, related to battle space management, is given in Figure 2. This includes: *picture compilation*, *threat evaluation*, *engageability assessment*, and *combat power application*. The last three functions are referred to as the Combat Power Management[2] (CPM) process (see grey part of Figure 2).

In this report, the focus will be on CPM. Nevertheless, for the completeness of the presentation, all the functions of Figure 2 are described in the sequel.

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[1] Source: Johns Hopkins APL Technical Digest, Vol. 16, No. 1 (1995)

[2] Also known as Threat Evaluation and Weapons Assignment (TEWA).

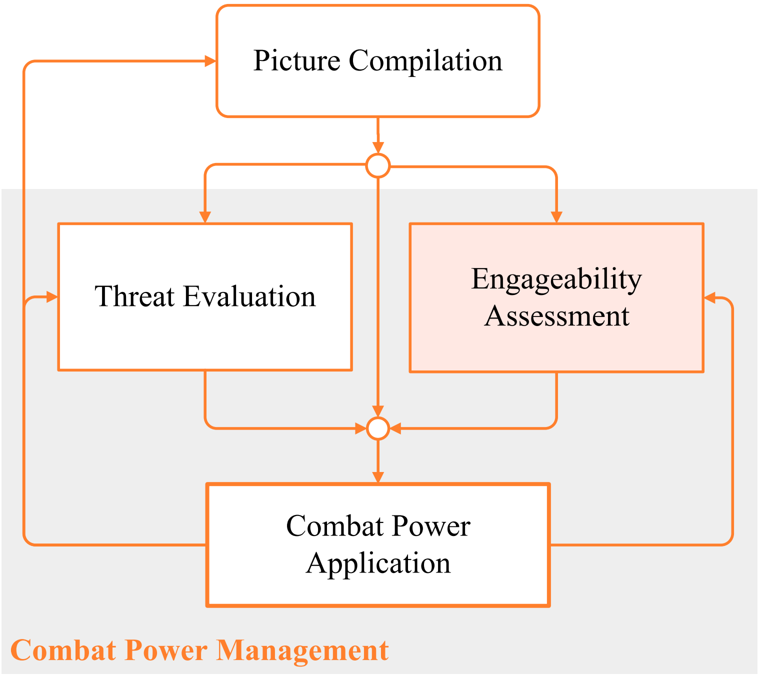

Figure 2: Global view of Command & Control process

2.1 Picture compilation

Picture compilation includes *object detection*, *object tracking*, and *object identification*. Object detection is very depending on the sensors performance, and may be based on data from a single sensor or a combination of several sensors. Object tracking uses the sensor data to optimally estimate the current kinematical properties of the object, and predict their future positions. Object identification (and classification) assesses the identity and the class of objects. This also results in the resolution of true objects from decoys or non-hostile objects.

The output of the picture compilation step is a tactical picture that gives a list of the objects with the Volume Of Interest (VOI), each associated with corresponding features. These features represent the main information, on which are based threat evaluation, engageability assessment, and combat power application.

2.2 Combat power management

To defend itself, a warship relies on a set of tactical resources, which we will refer to as combat power resources. These consist mainly of weapons, sensors, navigation, and communication systems. For a typical modern warship, such as the Canadian Halifax Class frigate, the combat power resources include hardkill (or lethal) and softkill (non-lethal) weapons. Hardkill weapons are directed to intercept their target and actively destroy it through direct impact or explosive detonation in the proximity of the target. Softkill weapons use techniques to deceive or disorient the target to cause it to destroy itself, or at least lose its lock on its intended target.

Combat Power Management (CPM) functionalities include, as depicted on Figure 2, *engageability assessment*, *threat evaluation*, and *combat power application*, which are described, in the reverse order, below.

2.2.1 Combat power application

Combat power application makes decisions on how to deal with the identified threats. This process can be subdivided into several sub-processes that include mainly *response planning*, *response execution & monitoring* and *outcome assessment*.

Response Planning – ensures that appropriate weapons are assigned to engage each target, including the supporting resources (such as sensors, communications, etc.). It results in a ranked list ($rank_E$) that gives the recommended order of engagements for each target. For two targets T_i and T_j,

$$rank_E(T_i, t) < rank_E(T_j, t), \qquad T_i, T_j \in \mathcal{T} \subset \mathcal{O} \tag{1}$$

means that, at time instant t, a decision has been made to engage T_i before T_j. $\mathcal{T}$ is the set of all potential targets, while $\mathcal{O}$ is the set of all non-friendly objects O_i within the VO. Note that the ranking is only important when the two targets are engaged by, or require, the same combat power resource.

Response Execution & Monitoring – is the process by which the planned response is executed. This also includes the execution monitoring functionality. Since the responses are executed in a dynamic environment, subject to uncertainty and changing goals and conditions, the actual execution contexts will be different from the projected ones[3]. Monitoring is required to help detect, identify and handle contingencies caused by uncertainty and the changing nature of the environment.

Outcome Assessment – represents the process by which the outcome of the executed actions are evaluated. This boils down to : (i) performing damage assessment (*e.g.*, capability) of engaged target(s); (ii) assessing damage inflicted to own-assets by opponent forces; and (iii) determining whether engagement objectives (*i.e.*, a series of actions) were accomplished (target is hard-killed/deterred/soft-killed, etc.).

Combat power application exploits the results of the threat evaluation and the engageability assessment processes presented in the next subsections.

2.2.2 Threat evaluation

Threat evaluation establishes the intent and the capability of the non-friendly entities within a certain Volume Of Interest (VOI). It refers to the ongoing process of determining if an

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[3] The ones that motivated the construction of the original response.

entity intends to inflict evil, injury, or damage to the defending forces and/or their interests, along with the ranking of such entities according to the level of threat they pose. It results in a list ($rank_T$) of entities ranked[4] according to the level of threat they pose. For two objects O_i and O_j,

$$rank_T(O_i, t) < rank_T(O_j, t), \qquad O_i, O_j \in \mathcal{O} \tag{2}$$

means that O_i is more threatening, at time instant t, than O_j. $\mathcal{O}$ is the set of all non-friendly objects O_i within the VOI.

The classification of objects as threats relies heavily on the use of the established picture of the situation, as provided by the picture compilation process (see § 2.1), and the available contextual information, which may range from the locations of vital assets and defended regions, attributes of platforms, weapons systems and surveillance systems, doctrine, intelligence reports, information about features of the terrain and the operations area, through to knowledge of the opposing force's structure and the recent history of its behavior in the operation area [1, 2, 3].

2.2.3 Engageability assessment

Engageability assessment (Figure 3) concerns the evaluation of own force's engagement options feasibility against non-friendly entities within the VOI. This process is intended to help the combat power application process (§ 2.2.1) by eliminating candidate solutions that violate one or more constraints, and which therefore will not be feasible.

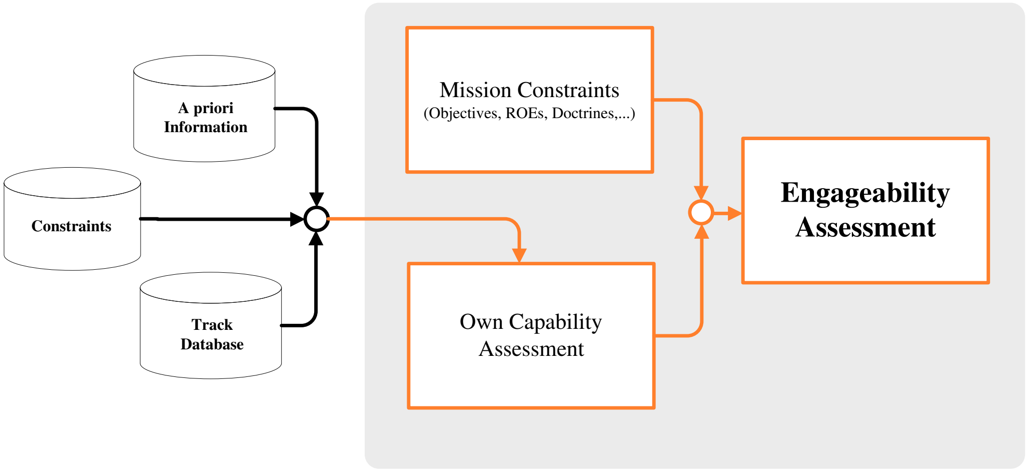

Figure 3: Engageability assessment process

Engageability assessment is the mirror process of threat evaluation (§ 2.2.2). The latter deals with red (hostile) objects and infers about their capability and intent, while the former is concerned by own-forces and friendly forces (blue) capability and the opportunity

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[4] Depending on the adopted solution, there may be more than one list, e.g. Low, Medium, High threat lists.

to counter non-friendly objects. This duality between threat evaluation and engageability assessment is shown in Figure 4.

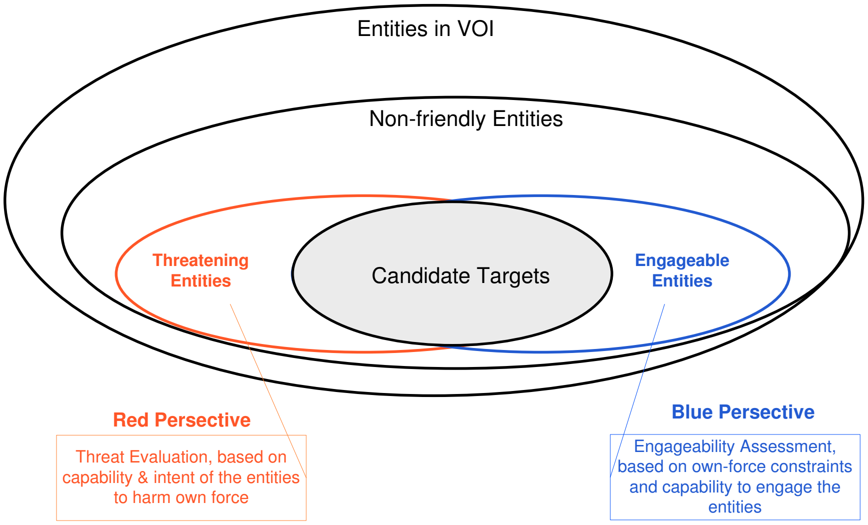

Figure 4: Dual perspective analysis

Figure 5 shows the portion (of a more global state diagram) that corresponds to the threat evaluation and engageability assessment functions, and the problems that need to be solved therein.

Objects that may cause harm to the own-force or to the protected assets transition from picture compilation to one of the two following states:

1. **Actual Threat** – this concerns threatening objects that were actually detected within the Volume Of Interest (VOI). 'Actual Threats' are then classified as 'High Threat', 'Medium Threat', 'Low Threat', based on their threat level. Threats are also ranked within each category. 'High Threats' are the ones that require the application of combat power. If they are engageable, they become considered for response planning.
2. **Potential Threat** – this concerns threatening objects that are not yet detected within the VOI, but are highly suspected to be (or expected to appear) in it. Upon detection, a 'Potential Threat' becomes straightforwardly a 'High Threat'.

Like threat evaluation, engageability assessment outputs a ranked list ($rank_O$) that orders the objects based on the availability and feasibility of own/friendly forces' options/opportunities against them. For two objects O_i and O_j

$$rank_O(O_i, t) < rank_O(O_j, t), \qquad O_i, O_j \in \mathcal{O} \tag{3}$$

means that own/friendly forces have more options, at instant time t, against O_i than against O_j, *i.e.*, O_i has a higher engageability score than O_j. We defined the engageability score as

$$E_s(O_i, t) >= 0 \tag{4}$$

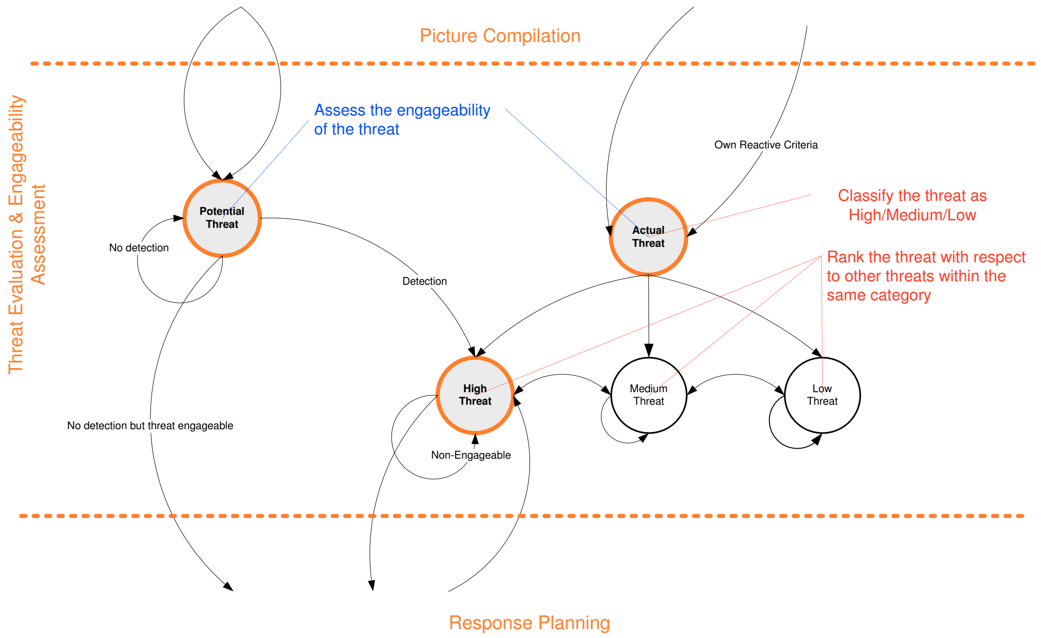

Figure 5: State diagram - Threat evaluation and engageability assessment

$E_s(O_i, t) = 0$, means there is no solution (option) for engaging O_i at time instant t. Also, for two objects O_i and O_j,

$$E_s(O_i, t) > E_s(O_j, t) \tag{5}$$

means that, at time instant t, own/friendly forces have a greater capability (*e.g.*, time window, fire solution, etc.) to defend themselves against O_i than O_j. Moreover, the feasibility of a sequence of engagements $[O_i, O_j, O_k, \dots]$ is defined by

$$E_s([O_i, O_j, O_k, \dots], t) = E_s(O_i, t) \times E_s(O_j, t + d_i) \times E_s(O_k, t + d_i + d_j) \times \dots \tag{6}$$

where $d_i, d_j, \dots$ are the durations of the engagements of $O_i, O_j, \dots$ respectively. Note that for $i \neq j$, $d_i \neq d_j$. With this definition, the re-engagement of the same object is possible only if

$$\begin{aligned} E_s([O_i, O_i], t) &= E_s(O_i, t) \times E_s(O_i, t + d_i) && (7)\\ &\neq 0 && (8) \end{aligned}$$

Several aspects can be taken into consideration during this process, such as Rules Of Engagement (ROEs), pairing appropriateness[5], window (range, time, ...), blind zones, ammunition availability, etc. The evaluation also considers target state and characteristics, characteristics of the defensive weapons and of their related resources, and mission goals. Risk, effectiveness and cost constraints can also be derived. In this regard, a feasible solution must verify a set of constraints, and will be eliminated if it violates any one. The

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[5] Ensure that weapon selection corresponds to threat type.

purpose of this evaluation process is to reduce the complexity of the problem and save planning time for combat power application, by discarding inconsistent candidate solutions. For example, a candidate engagement solution is retained if, for each considered engagement, the requested Fire Control Radar (FCR)[6] is available, the target to be engaged is within the range of the selected FCR, the interception will occur within the weapon envelope, and the target is not in the blind zones of both the FCR and the weapons.

The purpose of the process of engageability assessment (Figure 3) is to evaluate the feasibility of combat power application in response to the current tactical situation[7]. This ultimate goal can be decomposed into two sub-goals as follows.

1. Evaluate impact of mission context and constraints on combat power application
   (a) Evaluate impact of ROEs on combat power application
   (b) Evaluate impact of mission objectives and constraints on combat power application
   (c) Evaluate impact of other warfare on combat power application
   (d) Evaluate impact of tactical doctrine on combat power application
2. Evaluate own capability (*i.e.,* the potential of combat power resources). This goal can be decomposed into a hierarchy of sub-goals, as illustrated in Figure 6. The first layer of this decomposition is given below.
   (a) Determine state of readiness of combat power resources (threat independent)
   (b) Predict the performance of combat power resources to counter individual threats / threat clusters (threat dependent)
   (c) Assess the lethality of combat power resources(*a priori* information)

In Chapter 5, it is shown how the result of the engageability assessment process, and the underlying Constraint Satisfaction Problem (CSP), can be used for argumentation purposes to address the problem of the user's expectation failure. But first, the CSP and its application to the engageability assessment problem is presented in Chapter 3.

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[6] Hardkill weapons require FCR support. The engageability of targets using hardkill is very depending on the availability of FCR.

[7] *i.e.*, what combat power resources can be applied.

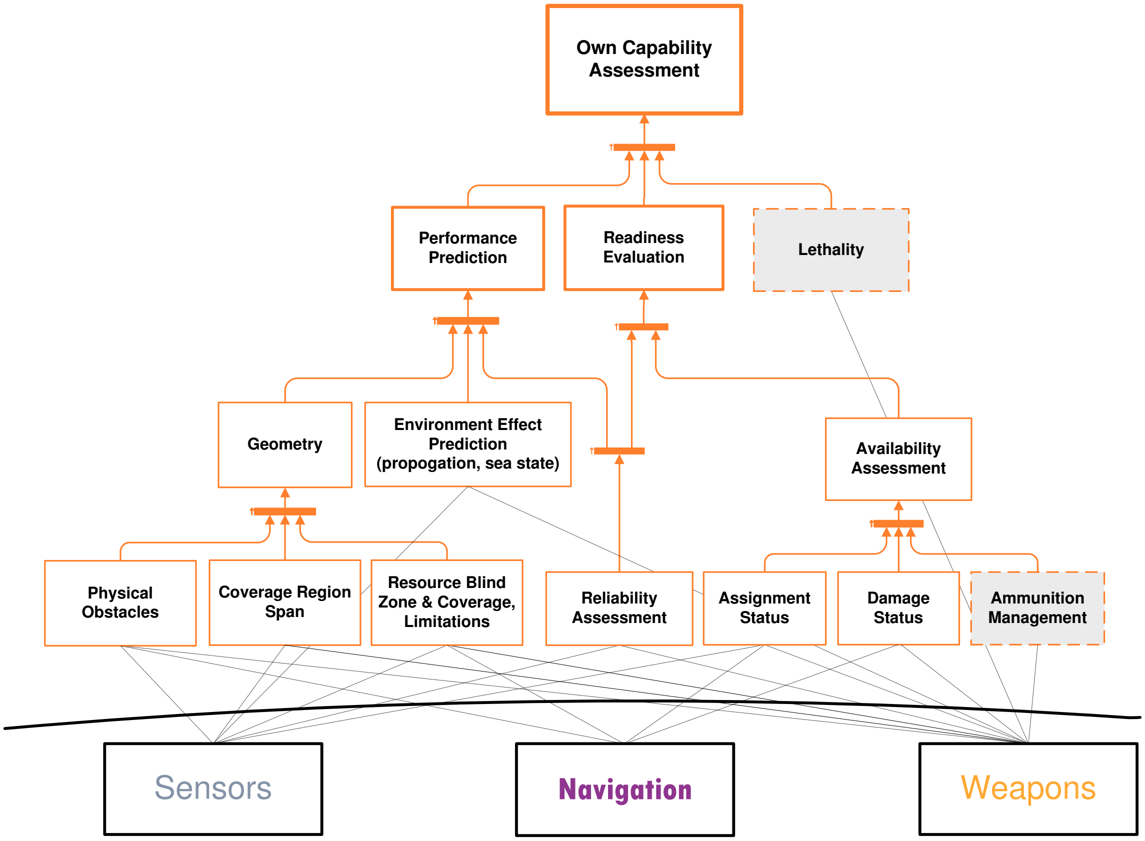

Figure 6: Hierarchy of goals for own capability assessment

3 Constraints in Combat Power Management

Most of the time, decision problems, such as Combat Power Management (CPM), which have to be solved under constraints, lead to sub-optimal solutions. The set of constraints defines a feasibility space, in which the automation algorithms will have to search for the best solution. The harder are the constraints, the smaller is the feasibility space, and the farther may be the solution from the optimal[8] (Figure 7). For the CPM problem, the feasibility of different options (*i.e.*, the feasibility region) is determined by means of the engageability assessment process (§ 2.2.3). The smaller is the engageability score E_s of the objects in the VOI, the smaller will be the solution space for combat power application, and the more distant will be the engagement plan from the operator's expected plan, hence the increasing risk of an *expectation failure* [4] .

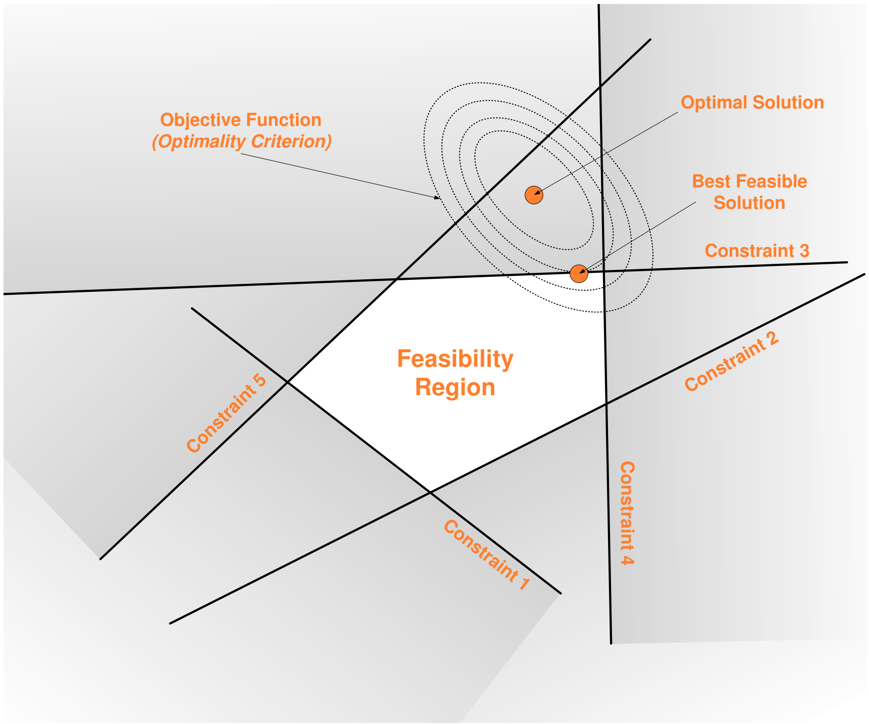

Figure 7: Optimal solution versus best feasible solution

An expectation failure (Figure 8) generally happens when the solution proposed by the (automated) system is different from the one the user had predicted. In this context, this phenomenon can occur when the set of constraints considered by the human operator is different from the one considered by the (automated) system. Given the very limited number of constraints he can consider at a time, a human operator often works on simplified (*i.e.*, relaxed) representations of the problems, which capture only a subset of the actual constraints. This is shown in Figure 8 where the user has omitted to consider Constraint 3. This brings the user to "wrongly" assume a larger feasibility region. A computer-based

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[8] Since the optimal may not belong to the feasible solution space.

DSS, which is not as limited as the human operator in its working memory, can handle a much larger number of constraints[9]. This difference can lead to a situation in which the solution considered by the operator is closer to the optimal than the one recommended by the DSS. The discordance between the two solutions can be justified by the number and the nature of constraints that would be violated if the DSS tried to get closer to the optimal in order to meet the operator's expectations.

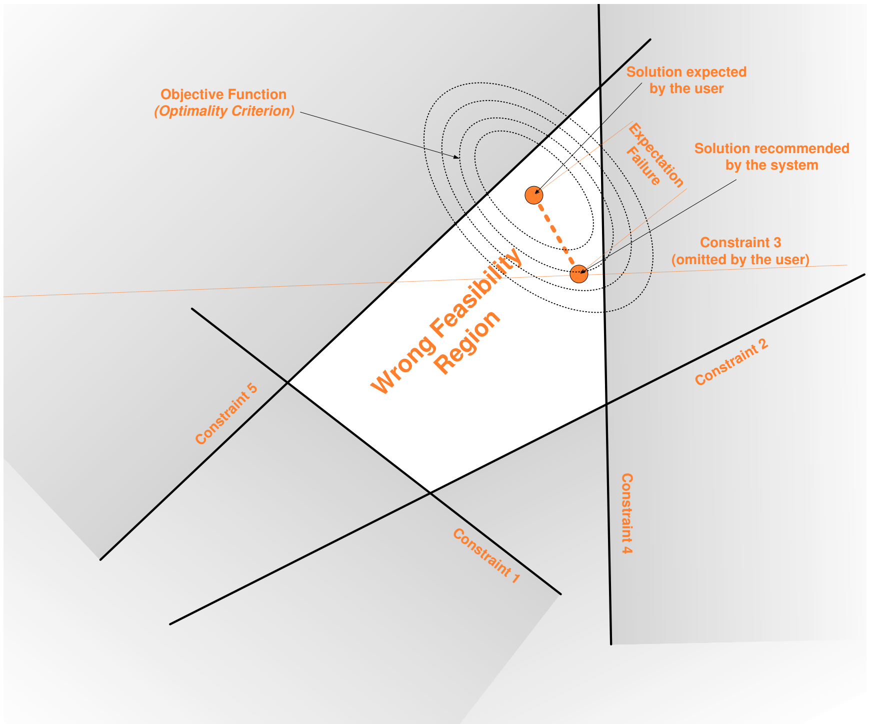

Figure 8: Constraint-based explanation of the user's expectation failure

The more restrictive are the constraints omitted by the user, the more difficult it will be for the DSS to bridge the gap between the two solutions. In anticipation of the operator's dissatisfaction, those constraints that would be violated if the DSS deviated from its solution can be stored at run-time during the problem solving. These are later presented to the operator by the argumentation module (see § 5) in response to his objections.

3.1 Examples of combat power management constraints

A constraint describes a relation that should be satisfied. The following give examples of constraints in the context of naval warfare. This list is not intended to be exhaustive and is only given to facilitate the discussion on the use of constraints as a base for argumentation in Combat Power Management (CPM) operations.

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[9] Naturally, we should also mention the fact that although the operator may not be able to handle all the relevant constraints, he may still consider one that was not integrated in the model of the system, in which case, the operator should be able to override the system's recommendation.

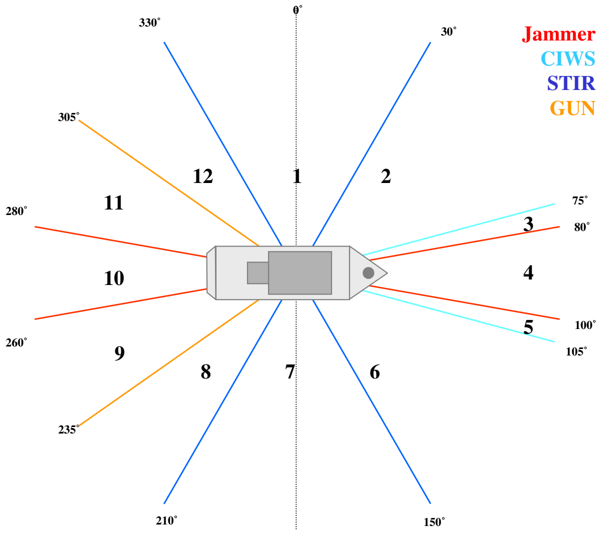


Figure 9: Example of blind zones for shipboard AAW combat resources

3.1.1 Spatial constraints

There are various kinds of spatial constraints on the combat power resources. In particular, weapon systems have minimum (R^-) and maximum (R^+) ranges from targets. For instance, a specific type of Surface-to-Air Missile (SAM) may be limited to a range of $R^- = 2$ km to $R^+ = 20$ km, and not be effective outside that range. As another example, jamming may be possible only within a range of $R^+ = 15$ miles ($R^- = 0$ miles).

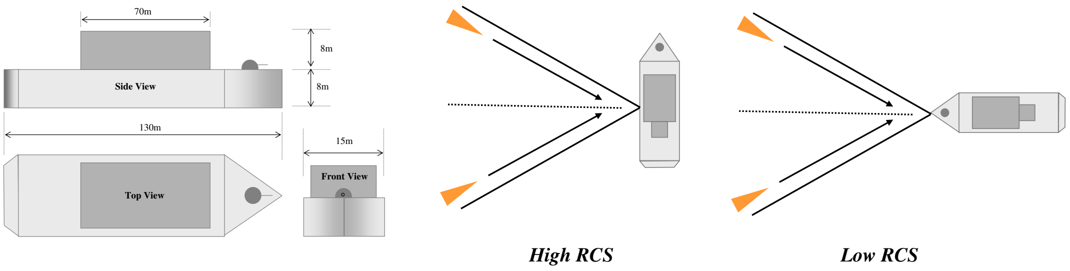
3.1.1.1 Blind zones

Some combat resources can have blind zones that must be eliminated before they are fired. They cannot view/reach particular threats and are therefore unable to operate when the carrying platform is not well positioned during the construction and the execution of a combat power application plan. The appropriate positioning of the platform can improve the effectiveness of the different strategies by clearing required blind zones. An example of blind zones for Canadian Frigates shipboard Anti-Air Warfare (AAW) combat resources is illustrated in Figure 9.

3.1.1.2 Signature reduction

The previous constraint imposes, to the defending platform, the use of actions that reduce its radar signature as seen by incoming target, since the capability of targets to lock onto the platform is directly related to the platform's geometry (Figure 10(a)), orientation (Figure 10(b)), and deployed combat resources (*e.g.*, STIR).

A combination of the geometry, the orientation, and deployed combat resources defines the defending platform's Radar Cross Section (RCS) as seen by the enemy. The selection of appropriate actions helps make own assets more difficult to be detected, identified, and tracked by enemy sensors. This can be achieved, as an example, through the minimization of all forms of radiated energy from own combat resources.



(a) Ship geometry (b) RCS based on position

Figure 10: Ship geometry and signature

3.1.1.3 No fire zones

This concerns constraints imposed by the presence, in the volume of influence, of other non-hostile platforms, *e.g.*, protected units, friendly platforms, neutral vessels, etc. (Figure 11). The deployment of combat resources in those directions may increase the -yet very high- risk of fratricides (*i.e.*, blue on blue) and/or collateral damages (*i.e.*, blue on white).

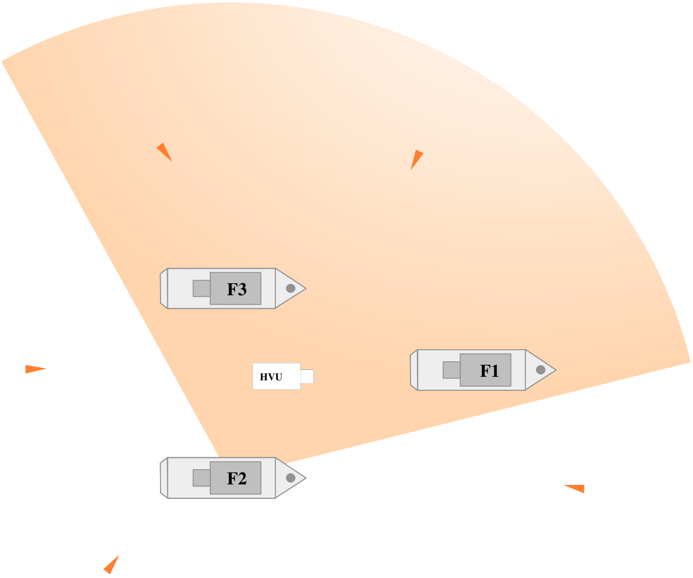


Figure 11: Example of no fire zone

3.1.2 Time constraints

Time constraints are also ubiquitous in the CPM problem. For instance, combat power resources must be deployed and ceased at the right time to have the right effect on the right targets, given the status, the position, and the type/characteristics of both the combat power resources and the targets.

Besides these unary time constraints, there are time constraints involving two or more actions or resources. These mainly consist in ordering constraints. For instance, some combat resource must be deployed first to enable the correct deployment of others. For example, a SAM can only be fired after a STIR has locked onto the target. Similarly, the IRG can be fired only after a STIR has locked onto the target. Some softkill strategies, such as the *damping*, impose strict ordering constraints on the deployment and the use of the chaff and the jamming systems.

Figure 12 illustrates an interval-based plan representation considered by the INCOMMANDS project[10]. As indicated in the figure, each action is associated with a time interval. This defines both of the above discussed classes of time constraints (*i.e.*, start/end and ordering).

3.1.3 Mutual-exclusion constraints

Avoidance of conflicts that may arise during the simultaneous use of resources are termed mutual-exclusion constraints. For instance, a single STIR cannot be used to point a gun and guide a missile at the same time, neither can it be used to illuminate two targets at very distant bearings.

3.1.4 Doctrines and rules of engagement

Doctrines and rules of engagement (ROEs) are in place to guide the use of different combat power resources. For instance, two STIRs will not be simultaneously assigned to the same threat. Neither a SAM, nor a gun, will engage a threat until kill assessment of a previous engagement is made. Such constraints impose further restrictions on the deployment of combat power resources.

3.1.5 Resource availability constraints

Most of the combat power resources are available in limited quantities. For the lifetime of a mission, some resources are renewable (*e.g.*, jammer or STIR), others are not (*e.g.,* SAM, IRG, or Chaff). Even for renewable resources, the availability remains limited at a given time. For instance, for the STIR, only a maximum of two fire control channels may be available at any time.

The deployment of combat power resources must consider the restrictions imposed by both the instantaneous and the long term (relatively to the mission duration) availability constraints.

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[10] Since the Operator Machine Interface (OMI) is still evolving, this representation must be considered as the current version at the time of this report.

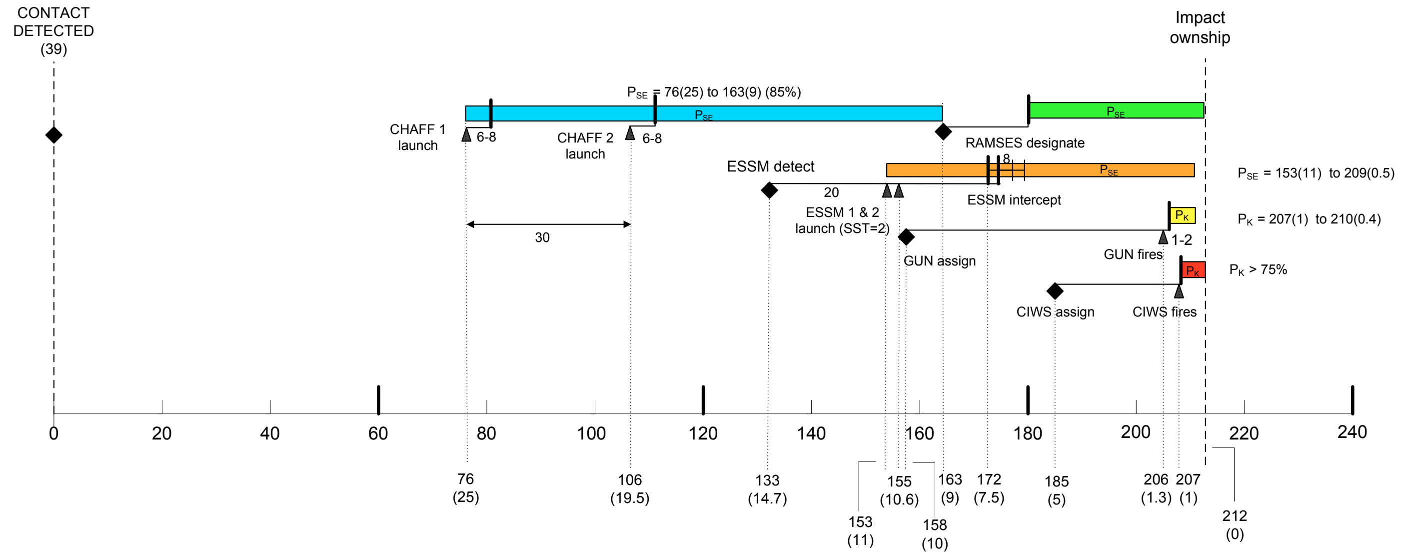

Figure 12: Combat resources time and ordering constraints

3.2 Constraint Satisfaction Problem

The Constraint Satisfaction Problem (CSP) offers an elegant and efficient framework to handle problems subject to constraints. CSP is the core of many applications in Artificial Intelligence (AI), and has been used in many areas, such as planning and scheduling.

A CSP is a problem that is formulated as follows [5, 6, 7]:

- Given
  - a finite set of variables (x_i)
  - a finite set of values (domains) $\mathcal{D}_i$ for each variable (x_i)
  - a finite set of constraints $\mathcal{C}_j$ on the possible values of variables. A constraint is an arbitrary relation over the set of variables.
- Find a complete assignment a_k of values to variables x_i consistent with their domains $\mathcal{D}_i$ and that satisfy the set of constraints $\mathcal{C}_j$.

This basic formulation can be extended in many ways. Adding a linear objective function $\mathcal{V}$ for optimization makes CSP either a Linear Programming (LP) problem or an Integer Linear Programming (ILP) problem when the constraints are linear and the domains of variables are, respectively, real or integer values. Valued CSPs add a utility value to each constraint, such that an assignment has a value equal to the sum of utilities to which it is associated. In this case, the CSP consists in finding an assignment that maximizes utility. A simple example of a CSP is given by the domains

$$x_1 \in \mathcal{D}_1 = \{1, 2\} \tag{9}$$
$$x_2 \in \mathcal{D}_2 = \{1, 2\} \tag{10}$$
$$x_3 \in \mathcal{D}_3 = \{1, 2\} \tag{11}$$

and the constraints

$$\mathcal{C}_1 : x_1 = x_2 \tag{12}$$
$$\mathcal{C}_2 : x_1 \neq x_3 \tag{13}$$
$$\mathcal{C}_3 : x_2 > x_3 \tag{14}$$

a solution to this problem is given by

$$x_1 = 2 \tag{15}$$
$$x_2 = 2 \tag{16}$$
$$x_3 = 1 \tag{17}$$

The assignment of a value a_k to each variable x_i, such as the one given by the equations (15) to (17), is called a complete assignment. Assignment of values to some variables is called a partial assignment. If a complete assignment is consistent with the domain values $\mathcal{D}_i$, satisfies the constraints $\mathcal{C}_j$, and optimizes the objective function $\mathcal{V}$ (if there is any), then it is a solution of the CSP. Most approaches to CSP are performed in the space of possible assignments, which is modeled as a tree with nodes corresponding to partial assignments and transitions corresponding to assignment of values to variables. These approaches rely on heuristics to avoid exploring the entire space of possible solutions [5, 6, 7].

An assignment $A = \{a_k\}$ is said to be consistent with respect to CSP if all the assignments a_k satisfy the set of constraints C_j.

When multiple planners (or agents, or decision makers) are in a shared environment, it becomes highly probable that constraints exist among their possible actions. A distributed constraint satisfaction problem (DisCSP) [8] is defined as a problem involving a set of agents, $A_1, \ldots A_n$, where each agent A_i is willing to enforce a corresponding set of private constraints C_j. The CSP must also handle inter-agent constraints C_{ij}. An assignment $A = \{a_k\}$ is said to be consistent with respect to CSP if all the assignments a_k satisfy both the private constraints C_j and the inter-agent constraints C_{ij}.

3.2.1 Soft CSP

So far, in the presentation of the CSP, only hard (or absolute) constraints have been considered. These constraints express strict restrictions on the assignment of values to variables. However, a large class of real-world CSP applications concern soft constraints. Instead of restrictions, the latter express preferences, and therefore deal with preferred solutions. Examples of hard and soft constraints are given in Table 1 for the engageability assessment problem.

Restriction (non-relaxable)	Preference (relaxable)	How to relax
- Rules of engagement	- Availability of supporting resources	-*Free resources*
- Availability of ammunition	- Damage status	-*Repair*
- Lethality	- Assignment status	-*Re-assign*
- Appropriateness of resource choice	- Coverage limitations (*Envelope, Blind Zone, Obstruction*)	-*Wait, move*
	- Predicted Performance (*e.g.*, probability of kill)	-*Wait*

Table 1: Examples of hard and soft constraints considered during engageability assessment

A soft CSP can be solved through constraint optimization, where soft constraints are encoded into an objective function $\mathcal{V}$ (or a cost) on individual variable assignments. To solve the problem, one seeks to maximize the number of satisfied soft constraints, and equivalently, minimize the number of violated soft constraints.

One very interesting approach to soft CSP is given by the concept of Constraint Hierarchies [9]. Constraint hierarchies were introduced to enable a user to specify constraints with hierarchical strengths or preferences. In this way, one can specify declaratively, not only the constraints that are required to hold, but also weaker, soft constraints at an arbitrary (but finite) number of strengths. Adding a strength-level to constraints helps to find a solution to over-constrained problems. Intuitively, the hierarchy does not allow the weakest constraints to influence the result. Moreover, constraint hierarchies make possible the "relaxing" of constraints with the same strength by applying, *e.g.*, weighted-sum, least-squares or similar comparators [10].

3.2.2 Reasoning with constraints

Approaches and techniques for solving CSPs can be classified into two main categories; those using search algorithms and those based on the consistency principle. Often the two are used in conjunction.

3.2.2.1 Search techniques

Search techniques explore the space of partial solutions (assignments). The most common algorithm for performing a search is backtracking [11]. Following a depth-first pattern, backtracking explores the space of partial solutions, and extends partial solutions by assigning a value a_i to one more variable x_i. In case of no possible consistent assignments (dead-end, that is $D_i = \emptyset$), backtracking occurs. Different improvements to this basic heuristic were proposed, including backjumping [12] and backmarking [13].

In this approach, the search problem can be summarized as follows: (i) the initial state is an empty assignment $A_0 = \{\}$, where no variable x_i has yet been assigned a value a_i (ii) a successor function $\mathcal{S}$, that allows moving in the partial solutions space, is executed. This is done by assigning a value a_j to one and only one unassigned variable x_j. This assignment must not create a conflict (*i.e.,* must satisfy all the constraints $\mathcal{C}_j k$) with all previously assigned variables x_k; and (iii) a test function τ, is executed that verifies if the current assignment is complete and that a solution is reached.

3.2.2.2 Consistency techniques

With consistency-based approaches, constraints are used actively to remove inconsistencies from the problem. Inconsistency is caused by values that cannot figure in any solution, *i.e*, violate one or more constraints.

Arc Consistency (1-consistency) – A constraint is Arc Consistent (AC) if, for any value of the variable in the constraint, there exists a value for the other variable(s) in such a way that the constraint is satisfied. A CSP is said to be arc consistent if all the constraints involved are arc consistent. To establish arc consistency in a CSP, every constraint must be revised. Revisions of constraints must be repeated until none of the domains is changed. This approach is referred to as AC-1 algorithm [14]. Variants of this algorithm[11] revise only the constraints involving the variable whose domains have changed. AC-3 inspired algorithms are the most commonly used in

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[11] Such as AC-3 [14], AC-4 [15], etc.

practice. The AC algorithms all achieve the same level of consistency but with different tradeoffs between simplicity, time and space complexity. Nevertheless, all arc consistency-based algorithms do not allow detection of all the inconsistencies in the CSP.

Path Consistency (2-consistency) – A path is defined by a set of arcs. A path is said to be consistent if, and only if, every arc in the path is consistent. In path consistency, only the constraints between the neighboring variables need to be satisfied. Also, it was proven [16] that it is enough to explore paths of length 2 (that include two arcs). To establish path consistency in a CSP, every path must be revised. Revisions of paths must be repeated until none of the domains is changed. As for arc consistency, this approach is referred to as PC-1 algorithm [14]. Variants of this algorithm[12] propose solutions that revise only a subset of paths to speed up convergence.

A graph (or network) is said to be globally consistent, if it is i-consistent for every i, where arc consistency and path consistency are special cases corresponding to $i = 1$ and $i = 2$, respectively.

3.3 Constraints and engageability assessment

Engageability assessment is described as the feasibility evaluation of the possible defensive strategies where one or more combat power resources are assigned to one or more targets. Generally, the evaluation should consider the state and characteristics of targets as well as the characteristics of the defensive combat power resources and of their related resources (*e.g.*, fire control radar). The evaluation should also be made with regard to the mission goals. Risk, effectiveness, availability and cost constraints can also be derived in the engageability assessment.

Engageability assessment can reduce problem complexity, save reaction time and maximize effectiveness, by discarding inconsistent candidate solutions and selecting the best compromise alternatives. This can be done by exploiting constraint propagation and consistency techniques described in § 3.2.2.2. Thus, a feasible alternative (*i.e.,* combat power assignment action or plan) must verify a set of constraints, and will be eliminated if it violates any one[13]. For example, an alternative is retained if for each engagement: ammunitions are available (availability constraint); requested FCR is available (availability and time ordering constraints); the target to be engaged is within the range of the selected FCR (time and spatial constraints); the interception will occur within the weapon envelope (spatial constraints); and the threat is not in the blind zones of the weapons (time and spatial constraints).

Since engageability assessment is about the evaluation of the feasibility of engagement actions and plans, it boils down to a CSP.

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[12] Such as PC-2 [14], PC-3 [15], etc.

[13] Here, it is assumed that all constraints are restriction (hard) constraints.

3.4 Constraints and argumentation

This section will briefly show how constraints and constraint satisfaction concepts can be used as decision support tools in the Combat Power Management (CPM) context. More specifically, they will be used to address the user expectation failure problem, which was introduced in the beginning of the current chapter. In fact, the system considers each constraint that it satisfies as an argument in favor of its recommendation. An example is given below.

One case where the expectation failure situation may happen is the following. For two objects O_i and $O_j (i \neq j)$

$$\begin{gathered} rank_T(O_i, t) > rank_T(O_j, t) \\ \& \\ rank_E(O_i, t) < rank_E(O_j, t) \end{gathered}$$

which means that O_j is more threatening than O_i, yet O_i is deemed as being of higher priority from the engagement perspective. This situation can be problematic because the operator will be more likely to rely on the threat list ranking ($rank_T$) for the engagement priorization[14]. Such engagement order cannot be presented to the operator without the support of some credible reasons.

A typical case that can justify the controversial recommendation above is when for two objects O_i and O_j,

$$rank_T(O_i, t) > rank_T(O_j, t) \tag{18}$$

that is, O_j is more threatening than O_i, but

$$\begin{aligned} E_s([O_j, O_i], t) &= E_s([O_j], t) \times E_s([O_i], t + d_j) \\ &< E_s([O_i], t) \times E_s([O_j], t + d_i) \\ &= E_s([O_i, O_j], t) \end{aligned}$$

which means that the engagement sequence (O_i, O_j) offers more possibilities to own-force than (O_j, O_i). If the user reasons on a relaxed version of the problem, he will probably not obtain the same engageability scores E_s as the DSS (due to the omitted constraints) and will consider the wrong engagement sequence (reverse order). The extreme case would be that the inverted engagement order is not feasible at all, that is

$$E_s([O_j, O_i], t) = 0$$

while

$$E_s([O_i, O_j], t) \neq 0$$

which means that the sequence (O_j, O_i) is not feasible[15].

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[14] This is a common practice in modern navies, where capability limitations are only considered at the later stage of combat power application planning process, with possibility of plan revision in case of an empty feasibility space (dead-end).

[15] This can be caused by the loss of opportunity on O_i during the engagement of O_j.

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4 Argumentation-based DSS

The Combat Power Management (CPM) process can be seen as a dynamic decision making process aimed at the successful exploitation of tactical combat power resources (*e.g.* sensors, weapons) during the conduct of C2 activities. From this perspective, decision support is defined to be a capability that is meant to assist operators in making well-informed and timely decisions while providing robust error detection and recovery. The DSS must be designed as to reduce the operator's cognitive overload and improve the overall effectiveness of the process [17].

However, the complexity of the CPM problem, the issues that are at stake, the high level of stress induced by resource and time constraints, the effects of stress and fatigue on attentional resources, and most important of all, the sense of responsibility with regard to one's decisions, can all lead to a situation of under-confidence, where the operator becomes overly concerned with the perils of a course of action [18]. In such a situation, it is unlikely that the operator will accept the (automated) system's recommendation if he does not fully understand it or if the recommendation is different from the alternatives he had considered [19], a phenomenon referred to as an expectation failure[16].

To be acceptable by the user, the information he is provided with needs to be presented in a comprehensible and convincing manner. Indeed, it is not only the quality of the recommendation made by the DSS that needs to be improved through more optimized processing, but also the user's *interpretation* of the quality of the decision [18].

This interpretation can be substantially improved if the system's knowledge structures are organized into a discourse that has a communicative value and that reflects people's natural way of presenting their reasoning. Endowed with argumentation capabilities, the system will have the capacity to expose its rationale and support its recommendation using sound arguments. The choice of argumentation as a persuasive tool, rather than the more classic explanation facilities, is justified by the fact that in this context, the system attempts to convince the user of a controversial conclusion [20].

4.1 About argumentation and its use in artificial intelligence

Van Eemeren and Grootendorst [21] provide the following definition for argumentation:

> *Argumentation is a verbal and social activity of reason aimed at increasing (or decreasing) the acceptability of a controversial standpoint for the listener or reader, by putting forward a constellation of propositions intended to justify (or refute) the standpoint before a rational judge.*

The theory of argumentation is a rich, interdisciplinary area of research lying across philosophy, communication studies, linguistics, and psychology. Its techniques and results have found a wide range of applications in both theoretical and practical branches of Artificial

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[16] See § 3 for a more detailed discussion.

Intelligence (AI) and computer science. These applications range from specifying semantics for logic programs, to natural language text generation, to supporting legal reasoning, to decision support for multi-party human decision making and conflict resolution. In recent years, argumentation theory has been gaining increasing interest in the Multi-Agent Systems (MAS) research community. On the one hand, argumentation-based techniques can be used to specify autonomous agent reasoning, such as belief revision and decision making. On the other hand, argumentation can also be used as a means of facilitating multi-agent interaction, because argumentation naturally provides tools for structuring, implementing and analysing sophisticated forms of interaction among rational agents [22]. As a result, argumentation can also provide a means of integrating communication with reasoning in a unified framework [23].

Argumentation has received great interest in the multi-agent systems community because the interaction between arguments can enable an agent to reconcile: (i) conflicting information within itself, (ii) its informational state with the changing environment, and (iii) conflicting information with other agents through communication.

Two points stand out when one talks of argumentation. First, the ultimate goal of argumentation is to resolve a "controversial" standpoint, a standpoint which is not accepted by all. This explains why it is argumentation rather than explanation, much more popular in the decision support systems domain, for which we have opted to address the expectation failure problem. As Walton [24] has written:

> *We argue that both explanation and argument contain reasoning, but that the key to the distinction lies in how that reasoning is used for a purpose. The purpose of an argument is to settle an open issue with another arguer with whom one is engaged in dialogue. Basically, the goal of an argument is to use reasoning to get this partner in dialogue to become committed to a proposition to which he was not committed at the beginning of the dialogue. The purpose of an explanation is to take something unfamiliar to this co-participant in dialogue and make it make sense to him by relating it to something with which he is familiar (or, at least, that makes some sense to him already). This is really the crux of the difference between argument and explanation, and the key to identifying each of them in a given case of discourse.* (Walton 1996: p30)

The standpoint, argued for, can be a proposition to believe, a goal to try to achieve, or a value to try to promote. Secondly, argumentation is a "reasoning activity", emphasizing that a particular process is to be followed in order to influence the acceptability of the controversial standpoint. One of the objectives of argumentation theory is to identify the criteria that define the reasonableness of the propositions put forward to reach this objective. In summary, argumentation can be seen as a normative interaction of different arguments with the aim of arriving at a consistent conclusion.

The second point has been a major inspiration for exploring different types of dialogues in MAS. Walton and Krabbe [25] describe a typology of main atomic dialogue types based on their preconditions (in terms of participants' beliefs) and the outcome that participants seek from the dialogue. Following are the main dialogue types, each with an informal explanation of its preconditions and goals:

Information Seeking – One participant seeks an answer to some question from another participant. The first participant believes that the second may have such answer.

Persuasion – Two (or more) participants have conflicting beliefs. One participant seeks to change another participant's belief.

Inquiry – A number of participants collaborate to reach an answer to some open question, that is, a question for which no one participant knows the answer.

Deliberation – A number of participants seek to decide on a course of action.

Negotiation – A number of participants, with conflicting interests and a need to cooperate, attempt to reach agreement over the division of some scarce resources.

In the formal specification of different types of dialogues, two main argumentation-theoretic concepts were adopted by the MAS community: dialogue-games, and argument schemes.

Dialogue games, inspired by the work of Hamblin [26], are some sort of conversation protocols that regulate argumentative inter-agent communication. The dialogue in a formal dialectic system is conceived as a turn-taking game between two players whose utterances are constructed in terms of the types of moves allowed in the game. Games are traditionally specified in terms of sets of rules. Such a system would mainly consist of [27]:

- a set of moves (*e.g.*, challenge, assertion, question);
- a commitment store for each party engaged in the conversation;
- a set of commitment rules defining the effect of the moves on the commitment stores;
- a set of dialogue rules regulating the moves; and
- some termination rules defining when the dialogue ends.

Another main inspiration from argumentation theory in MAS is the notion of an argumentation scheme [28, 29]. These are schemes that capture stereotypical (deductive or non-deductive) patterns of reasoning found in everyday discourse. For example, Walton specifies 25 argumentation schemes for common types of presumptive reasoning (*argument from commitment, argument from analogy, argument from precedent, argument from expert opinion*, and so forth). The most useful aspect of argumentation schemes is that they each have an associated set of critical questions. These critical questions help identify various arguments that can be presented in relation to a claim based on the given scheme. Hence, while a scheme can be used to establish a "stance", the set of critical questions help build communication structures about that stance.

An example of an argument scheme called the **Argument from Sign** [28] is given below:

Minor premise – Given data represented as statement 'A is true in this situation'.

Major Premise – Statement B is generally indicated as true when its sign, A, is true, in this kind of situation.

Conclusion – Therefore, B is true in this situation.

Argumentation schemes offer a number of useful features to MAS communication. Their structure helps reduce the computational cost of argument generation, since only certain types of propositions need to be established. This very feature also reduces the cost of evaluating arguments.

Argumentation schemes are variants of a basic argument structure that Toulmin [30] has conceptualized in order to capture practical reasoning. In the next section, we show how this structure can be used to expose the rationale used by a decision support system.

Toulmin's argument structure can capture the inferential nature of reasoning used in Combat Power Management (CPM), and more specifically in the engageability assessment process[17]. However, as we later discuss, a different approach will have to be adopted since, in the context that is of interest to us, what determines the strength of a support for a claim is how well it can respond to specific objections, and not, for example, how widely accepted it is. In the following, we first show how Toulmin's general model can be used to outline an argument based on the information provided by the engageability assessment. Then we show how this basic inferential structure can be augmented with a dialectical component adapted to a time-constrained decision support context.

4.2 Toulmin's model

Toulmin proposes an argument structure that reflects the natural procedure by which claims can be argued for. The model is composed of six elements (Figure 13) that depict the move from a set of premises to a conclusion.

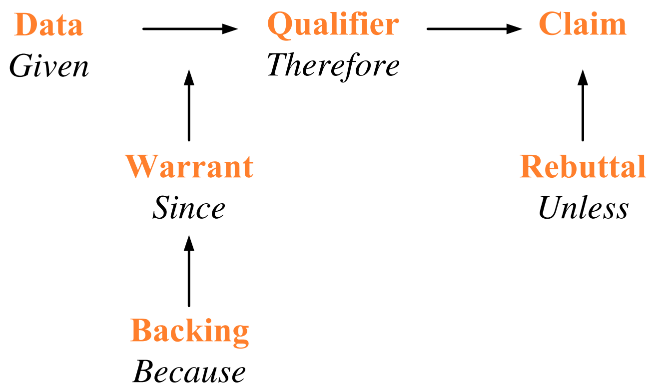

Figure 13: Toulmin's model of argument

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[17] Solutions are inferred from the intermediary results input by lower-level processes, as shown in Figure 6.

In addition to the premise-conclusion structure (*data* and *claim*), Toulmin identifies several components that support the inferential relation. The *warrant* has the function of a rule of inference, licensing the conclusion on the basis of the arguer's data or grounds. The arguer can invoke a *backing* if the warrant is challenged or insufficient. The modal *qualifier* is a word or phrase that indicates the force of the warrant, whether it holds universally, usually, presumptively or merely sometimes. Finally, the *rebuttal* is a peculiarity of arguments whose warrant justifies only a presumption that the conclusion is true. Such presumptions are subject to rebuttal, which accounts for the fact that some exception-making condition might be applicable [31]. A description of the model is provided in Table 2.

Data (D)	Statements specifying facts or previously established beliefs about a situation about which the claim is made.
Qualifier (Q)	Statement that expresses a causal relation between the data and the claim and possibly a degree of certainty associated to the claim.
Claim (C)	An assertion or a conclusion presented to the audience and which might not meet the audience's initial beliefs.
Warrant (W)	Statement which justifies the inference of the claim from the data.
Backing (B)	Set of information that assures the trustworthiness of a warrant. A backing is invoked when the warrant is challenged.
Rebuttal (R)	Statement presenting a situation in which the claim might be defeated.

Table 2: Description of Toulmin's model

The model expresses plausible reasoning, captures inferential mechanisms, can outline a decision situation and preserve it for future use, and finally, can be used as a basis for explanation generation. Ye & Johnson [32] have shown that the model outlines the discrete response steps that an explanation facility should follow in order to achieve user acceptance of a recommendation. As a matter of fact, the *data-qualifier-claim* structure in Toulmin's model can provide a *trace explanation* which is a record of the (rule-based) system's rule-invocation history. A trace explanation, however, does not provide insight into the underlying rationale of such inferential rules. The warrant and the backing can both, at different stages, justify the inferential leap by grounding the rule in domain knowledge, thus providing what is called a *deep explanation*. Finally, the same components can be used to provide visibility into the system's resolution strategy, justifying why information is processed in a certain order and how reasoning steps contribute to high-level goals. This would be a *strategic explanation*.

Toulmin's model has been extensively cited in argument studies, as well as in Artificial Intelligence (AI), and has even been applied to military problems such as theater missile defense [33]. In the next section, we explain how it can be applied to the engageability assessment process.

4.3 Example of application of Toulmin's model

Table 3 presents an example of the application of Toulmin's Model to the Combat Power Management (CPM) problem. The example is based on the concept of engageability assessment, formalized in subsection 2.2.3. The results of engageability assessment, based on constraints violation avoidance, are used as intermediary results to justify recommendations for the weapon assignment phase.

Data	Two objects (O_i, O_j) have been detected within VOI and assessed hostile to own/friendly forces. Object O_j has been assessed to be more threatening than O_i. Options against both objects have been evaluated. As a result, the engagement order (O_j, O_i) has been deemed non-feasible, while (O_i, O_j) offers options.
Qualifier	Consequently
Claim	The combat power application module recommends the engagement order (O_i, O_j).
Warrant	Since by the end of engagement of O_j, O_i will enter the Fire Control Radar (FCR) blind zone, while by the end of engagement of O_i, O_j will still be within the FCR coverage area.
Backing	The Anti-Ship Missile (ASM) nature of threats requires the use of Surface-to-Air Missile (SAM) to counter them. FCR support is mandatory for the SAM's guidance and threat illumination.
Rebuttal	Unless probability of kill (P_k) on O_i is much lower than for O_j.

Table 3: Example of Toulmin's model application

The controversial nature of the claim (recommending an engagement order which does not correspond to the threat level of the objects) requires that the inferential relation be licensed with a warrant. In Toulmin's model, a warrant is a general law ('major premise' in Walton's argumentation schemes) which licenses the move from the data to a claim. Here, the system has to warrant the recommendation with specific information. Also, the domain knowledge provided in the backing will be of little use for the operator who will rather want to know what are exactly the factors that the system has considered and how valid they would be if the operational conditions were modified. As a matter of fact, the warrant may be challenged, not because the reason it provides is not good enough, but because the operator may object that the conditions under which that warrant holds can be changed.

Based on these remarks, we propose to augment the premise-conclusion structure with a dialectical component that will enable the Decision Support System (DSS) to handle such situations.

4.4 Dialectical argument

The functional account of Toulmin's model is a deductive, rather than a dialectical model of argumentation in that it does not take into account the beliefs, opinions or reasoning schemes of the audience it is addressed to. In a dialectical scheme, the arguer has to consider possible counter-arguments. In Toulmin's model, although the rebuttal accounts for the possibility of the defeat of the argument, it simply shows that an exception-making condition might be applicable. This is a condition that the arguer contemplates, but it is not a condition that he considers as being the object of his audience's belief. Reasoning on the beliefs of the audience is the core of dialectical reasoning.

As Johnson [34] has argued, because the conclusion may not meet the initial beliefs of the audience, an arguer will need to do more than put forward some supporting statements. One will need to respond to objections and alternative positions. The *illative core* (premise-conclusion) of the argument, as he calls it, does not by itself address such questions and can therefore not constitute a complete argument. Accordingly, he argues for a 'second tier' of argument, the *dialectical tier*, in which the arguer discharges his dialectical obligations.

Thus, Johnson considers that the dialectical activity is not only a feature of argumentation as a dialogue between two conflicting human or software agents, but an integral part of argument structure. This is not a position defended by all argument theorists. However, the combination of the two components does reflect the structure of a prototypical argumentative text/discourse [35], where in absence of a genuine dialogue with the audience/readership, the argument proponent speculates on possible objections and puts forth arguments against them.

4.4.1 Model of argument with a dialectical component

The dialectical component can be viewed as an *argument-objection-response* to objection sequence. This tripartite structure of justification warrants the inference from data to a claim, which in the case of a Decision Support System (DSS) is a solution or recommendation. This is illustrated in Figure 14.

Using this model, we propose to design the DSS so that it can anticipate possible objections on the part of the operator and prepare its responses to those objections. As we see in the next subsections, the constraints violation avoidance principle employed by the engageability assessment process can be used as a basis for argument/response generation. This mechanism can significantly enhance the DSS's persuasive capacity.

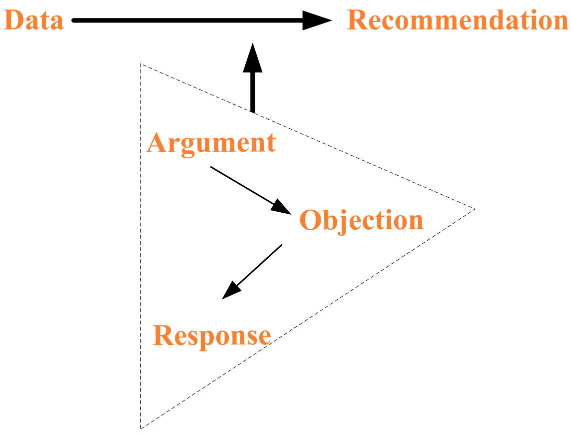

Figure 14: Inferential model of argument with a dialectical component

As pointed out in Girle et al. [36], good advice, apart from coming reliably from an advisor with relevant expertise, has at least three essential features and it is vital that DSSs have these features.

1. the advice should be presented in a form which can be readily understood by the decision maker;
2. there should be ready access to both the information and the thinking that underpins the advice; and
3. if decision making involves details which are at all unusual, the decision maker needs to be able to discuss those details with their advisors.

Any argument structure fulfills the first two requirements. By using the dialectical model, the proposed system attempts to integrate the third feature, that is, offer the possibility of recovering from an expectation failure situation, created by the unusual character of the recommendation.

The third feature, as the authors [36] remark, 'draws the decision maker into the process, so the advice is not *over against* the decision maker, authoritarian rather than authoritative, final rather than part of a process. There needs to be the possibility of joint deliberation about what should be done. If the decision maker is involved, by supplying *local information*, questioning the rationale behind advice, and discovering the deeper reasons behind the advisor's recommendations, then the final decision will be more considered and more likely to be correct.'

4.4.2 Dialectical argumentation in a decision support context

As discussed before, dialectical argumentation has essentially been applied to the design of multiagent systems where a group of intelligent software agents interact to achieve some common or separate goals. Several recent works have proposed argument models that software agents can use to carry out negotiation activities. Argumentation is a key mechanism to bring about agreement in non-cooperative situations when agents have incomplete knowledge about each other or about the environment.

However, dialectical systems are more concerned with the validity rather than the effectiveness of the arguments. A dialectical discussion supposes that the the proponent builds his argumentation on what he considers to be the opponent's beliefs, values, or preferences. One work that is concerned by this and is moreover grounded in a domain which is relatively close to decision support is the advice giving system proposed by Grasso et al. [37]. In this system, communicating agents try to convince a partner of a point of view they wish to promote by using the latter's preferences. These agents, however, do not engage genuine dialogues with real users, and as far as we know, no argumentative agent really does, because of the difficulties inherent to natural language processing.

Nevertheless, in dialectical systems, agents do reason, through commitment stores, on the input provided by each other. The argumentation system proposed here does not. Although the system can predict possible objections, it does not *process* that information. The user's input in no way changes the system's knowledge structures. As explained in the next chapter, the system's computational power is overwhelmingly superior to that of the operator. Also, its arguments are based on constraints which, once made known to the operator, can be ignored, but can possibly not be refuted. Thus, the only requirement regarding the system is to understand the user's objection and rapidly persuade him of the soundness of its reasoning by putting forth accurate arguments.

The exchange, as such, is bounded, so to say, and this is mainly due to three factors:

1. the time-constrained nature of the decision making context;
2. the fact that the parties are not self-interested and are engaged in a collaborative problem solving process where a solution has to be quickly reached; and
3. the fact that both parties (the user and the system) share the same domain knowledge and the space of possible solutions can be rapidly exhausted;

Concerning the third point, as Girle et al. [36] emphasize, dialectical argumentation provides a means to address the problem of resource limitations within the guidance system itself, for example, constraints on the time within which a course of action must be suggested. Thus, one need not address all conceivable counter-arguments to a claim (*e.g.*, all those based on conflicts of interest), but argumentation and deliberation may be limited to only those counter-arguments raised in the debate. In this way, a more efficient use of resources can result, since one can quickly focus on the extant differences of opinion instead of on all possible differences. The system proposed here precisely only considers the counter-arguments that the operator may present to a given argument in a given situation. The space of possible solutions reduces *de facto* the argumentative space.

Another characteristic of the proposed system is that it displays a strategical behavior. Lately, researchers have been looking at argumentation dialogue strategies which concern the choice of an utterance in order to bring about some desired outcome. This is particularly important in persuasion dialogues. For example, Amgoud et al. [27] propose a system in which, given the argumentative profile of an agent (careful, confident, etc.), the agent may prefer to use a specific strategy, the determination of which boils down to questions such as: 'Should the agent continue to challenge the proponent or propose its counter-argument?' 'Which element of the support is it best to challenge?', 'Which counter-argument should be presented?', 'What would be the choice if the time of the debate was limited?', etc.

The problem of strategy is elegantly handled here. As we will see in Chapter 5, because of the lack of time, the system advances its best arguments first and challenges the operator only if the latter has objections. Also, arguments or responses to objections are presented relatively to their justificatory strength, which is a function of the constraints they express. The interplay between the engageability assessment process and the argumentation module is detailed in the next chapter.

5 Argumentation module

The proposed argumentation module is depicted in Figure 15. The engageability assessment process evaluates the set of possible solutions and discards those which would violate one or more constraints. The results of this constraints violation avoidance process are stored in a database and used as arguments to be presented to the user.

The argumentation module can display its dialectical skills using both proactive and reactive interaction modes. The *response coordinator* selects and coordinates dynamically the two modes. The difference between them lies in the fact that the dialectical cycle is initiated by the argumentation module in the proactive mode, while it is initiated by the user in the reactive mode. An argument is called response when provided reactively (in response to an objection). The numbers in Figure 15 show the chronology of the events for each mode. The role of the *response coordinator* is twofold: i) receiving the user's objections, and ii) coordinating the deployment of the interaction mode.

Having prepared itself for all possible cases of disagreement, the coordinator will first activate the proactive mode and proceed by presenting its best arguments. These are those arguments that are the most persuasive responses to what it considers to be the most likely objections. It will then shift to a reactive mode and provide justification only upon user's further objections. This will be the case if the operator formulates more specific objections or if more detailed or low-level information is needed.

Naturally, the operational context described here, where time is a critical issue, does not allow for a genuine dialogue between the system and the operator and therefore models, such as that of the deliberation dialogue [38], cannot be applied.

In the above-described process of argumentation, the nature of the constraints plays a major role in the weight of the justification (*i.e.*, its persuasive power). Logically, avoiding the violation of restriction (hard, non-relaxable) constraints will have a higher justificatory power than avoiding the violation of preference (soft, relaxable) ones. From an argumentation perspective, it is assumed that the former constitutes a sufficient condition for the conclusion to obtain, while the latter does not. It is also expected that the user will object to the arguments based on preference constraints by asking the system to modify them so that they can be satisfied. Examples of such possible objections are given in the column "How" of Table 1.

For the Combat Power Management (CPM) problem, the engageability assessment module will have to verify a set of N_R relaxable (soft) constraints and a set of N_{NR} non-relaxable (hard) constraints, for a total of $N_R + N_{NR}$ constraints. The set of non-satisfied constraints will be used to constitute dynamically the system's arguments/responses database (see Figure 15). Based on the content of this database, the response coordinator provides proactively a maximum of N arguments to the user, using argumentation schemes. Given their higher justificatory power, priority is given to arguments related to the non-relaxable (hard) constraints. The presence of at least one non-relaxable (hard) constraint that could be violated eliminates the need to consider arguments related to relaxable (soft) constraints. If

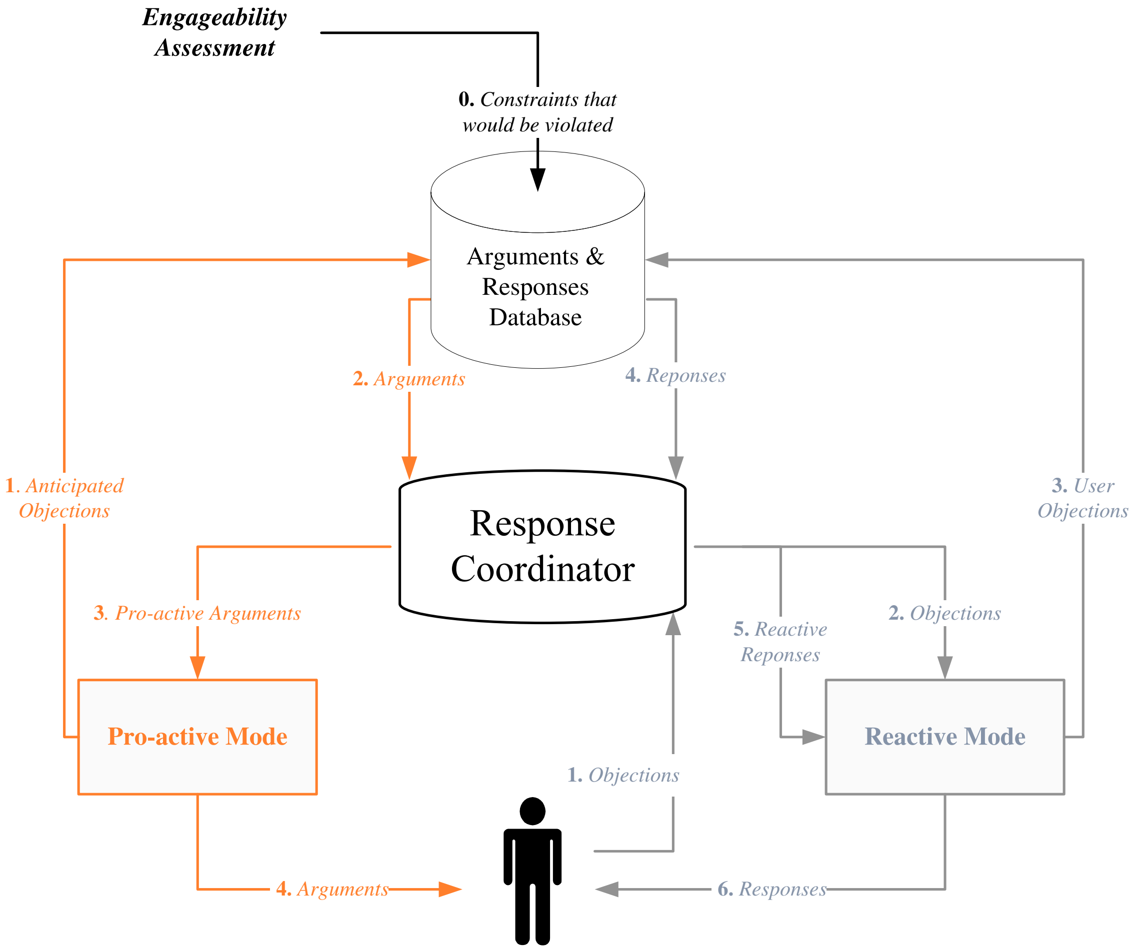

Figure 15: Argumentation module architecture

there is no such non-relaxable (hard) constraint, the system will present the N arguments related to relaxable (soft) constraints that are deemed most likely to be mentioned by the user[18]. The remaining set of constraints that may not be satisfied will be provided reactively on a one-by-one basis, should the user continue to object to the system's recommendations.

To illustrate the idea, let us take the extreme case of the example presented previously, where two objects (O_i, O_j) have been detected within VOI and assessed hostile to own/friendly forces. Object O_j has been assessed more threatening than O_i. Engageability for both objects has been evaluated. As a result and based on the different constraints, engagement of O_j is deemed non-feasible (*i.e.*, $E_s(O_j) = 0$) and only O_i is engageable and will be engaged ($E_s(O_i) \neq 0$).

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[18] The constraints, hard and soft, are ranked beforehand. This ranking provides, for hard constraints, the order in which the constraints are checked. For soft constraints, it provides, the order in which the related arguments are presented to the user

Situation 1 (Sufficient Arguments) – this corresponds to the case where one or more restriciton (hard) constraints would not be satisfied. For example, if ROEs prevent own-force from engaging O_j, any solution that includes engagement action on O_j will not satisfy this hard non-relaxable constraint. This information can be used as a sufficient argument that cannot be objected to by the user, and no further arguments will be required. This argument is presented proactively, and there is no need to consider arguments related to preference (soft) constraints.

Situation 2 (Non-sufficient Arguments) – this corresponds to the case where all restriction constraints are satisfied and one or more preference constraints are not satisfied. Based on the set of constraints that would be violated by engagement action on O_j, the DSS decides to present proactively the two ($N = 2$) following arguments, regarding the recommendation of not engaging O_j. These arguments are:

- O_j lies within the blind zone of the only available Fire Control Radar (coverage limitation constraint), and
- The other Fire Control Radar is assigned to another target (assignment status constraint).

The other constraints that would be violated, if any, would be used by the reactive mode.

Given the relaxable nature of the constraints they are related to, these arguments are not sufficient. As a consequence, it is expected that the operator will object, asking why the constraints are not relaxed, so that the feasibility space can be extended (*i.e.*, the engageability score $E(O_j)$ increased). Examples of objections/responses that may be used in the reactive mode of the system following the first argument, are given below (see Table 1).

Objection 1 (*Wait*) – meaning: wait until the object O_j gets out of the Fire Control Radar blind zone and provide engagement solution. An example of a possible response to this objection is:

- Object will get out of the weapon range as well.

Objection 2 (*Move*) – meaning: move the ship to clear blind zone. Examples of possible responses to this objection are:

- Physical obstacle prevents from moving.
- Not enough time to move.
- Jeopardizes other engagements that are in progress.
- Increases ship's Radar Cross Section (visibility by the enemy sensors).
- Puts more threatening objects within blind zones.

The above list gives examples of potential reasons that may render the decision of moving the ship (one of user's anticipated objections) not feasible.

The examples discussed above show how the system can exploit knowledge of the domain to justify a recommendation that does not meet the initial beliefs of the operator. The power of the argumentation module is based on two features. One is the use of constraints as potential arguments. Constraints can not be refuted and therefore the arguments that are built on those constraints directly appeal to the operator's common sense. The other feature is the order in which the arguments are presented to the operator. By using the strength of the arguments, determined itself by the nature of the underlying constraints, as a basis to plan its argumentation, the system clearly displays a strategic behavior, which makes the overall interaction considerably more efficient in a very time-constrained environment.

6 Discussion and conclusion

This report showed how the process of threat evaluation and weapons assignment in tactical naval command and control can be supported by an argumentation-based decision support system, based on Toulmin's model of practical reasoning, augmented with a dialectical component. This work fosters new cross-disciplinary discussion by proposing an innovative combination of artificial intelligence and argumentation theory.

By adopting a multidisciplinary approach to decision support, this work showed how a system can, not only contribute to a better quality of decision, but also a better user perception of its capabilities. The CSP approach is in itself a very efficient way of handling the CPM problem. It was shown how this technology can be used to assist the operator in making error-free and timely decisions. The report described, for the first time, the engageability assessment process from a military perspective, within the Naval C2 domain, and from a technological perspective, as a particular case of CSP.

This document also provided a brief overview of the theoretical aspects of argumentation and its use in the field of artificial intelligence and that of decision support. The two approaches were used to propose an argumentation capability, which not only expresses the soundness of the system's reasoning, but also engages a dialectical exchange with the operator. By anticipating possible objections, calibrating its own arguments, and finally, employing proactive and reactive argumentation, the system displays interactional skills that are accurate and effective enough to support deliberative decision making in a time-constrained context such as CPM.

It was shown how by adding an argumentation layer, the results can be presented in a way that can improve the operator's interpretation of the system-provided solution. The organization of the system's knowledge into argument structures provides insight into the system's states, procedures and goals, and shows the extent of its domain knowledge and capacities. A better understanding of these features will hopefully result in a more efficient use of the system proposed.

Follow-on work will have to investigate ways in which the user can feed the system with new information or new arguments, thus affecting the assessments. For the time being, the user's input only triggers relevant arguments focusing on the objection raised. The conversion of constraints into argument structures is another point that requires more in-depth investigation. Practical operational factors will have to be taken into consideration as well. Time is the biggest operational constraint in a tactical context. Therefore, the degree of human-system interaction must be carefully measured. The relationship of the operator with an 'arguing' system must also be evaluated in terms of user perception, user confidence, and trust.

These issues will be addressed within the project *Advisory Threat and Intent Assessment in Littoral Joint Context*, that builds upon and extends the work presented in this document. The objective of this project, conducted in collaboration with Canadian academia and industry, is to implement, test and validate the concepts discussed here, with force-level threat evaluation as a target application. Threat evaluation, in naval operations, consists in observing the behavior of potentially hostile entities in order to determine their goals, plans, intent, capability and opportunity for causing damage to protected assets. This process is conducted by human operators based on information provided mainly through a tactical picture. Given the very high complexity of naval task-force threat evaluation tasks, a decision support system that can enhance decision quality by reducing the risk of errors for operators, and gain their trust by providing insight into the system's rationale through argumentation is investigated.

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List of acronyms

AC	Arc Consistency
AI	Artificial Intelligence
ASM	Anti-Ship Missile
AAW	Anti-Air Warfare
C2	Command & Control
CCS	Command & Control System
CPM	Combat Power Management
CSP	Constraint Satisfaction Problem
DisCSP	Distributed Constraint Satisfaction Problem
DRDC	Defence Research & Development Canada
DSS	Decision Support System
FCR	Fire Control Radar
ILP	Integer Linear Programming
IRG	Intermediate Range Gun
LP	Linear Programming
LPI	Low Probability of Interception
MAS	Multi-Agent Systems
PC	Path Consistency
RCS	Radar Cross Section
ROE	Rules Of Engagement
SAM	Surface to Air Missile
STIR	Separate Tracking and Illumination Radar
TEWA	Threat Evaluation and Weapons Assignment
VOI	Volume Of Interest

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H. Irandoust, ; *A. Benaskeur*,

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This report describes an argumentation-based Decision Support System (DSS) that can assist the operator with target engagement within the Combat Power Management (CPM) process. It is shown how the information gathered and analyzed during the engageability assessment, a process based on the constraint satisfaction principle, can be exploited by an argumentation module. Using a dialectical model, the argumentation module enables the DSS to anticipate and respond to the operator's objections to its recommendations, and thus convince him of the soundness of its reasoning.

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