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CASAP

Sharing of responsibilities between human and computer

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DRDC Valcartier

Defence R&D Canada – Valcartier
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Abstract

A distributed Decision Support System (DSS) was implemented to assist the Air Operation Centre (AOC) staff in dealing with events of counter-drug operations: to intercept drug smugglers violating the Canadian airspace, in co-ordination with different services and parties. This DSS, called *Commander's Advisory System for Airspace Protection* (CASAP), aims at helping the AOC team to describe and share information about such an incident, developing pertinent Courses Of Action (COAs), evaluating these COAs and determining which one is most appropriate. An important element of this system is a semi-automated decision aid module for the selection of COAs. This module was developed to assist the Commander in prioritising and analysing COAs. This document briefly presents CASAP and the decision aid module approach used (Multiple Criteria Decision Aid (MCDA)). Finally, the implemented sharing of responsibilities between the MCDA analyst, the decision-maker (the Commander) and the computer is discussed.

Résumé

Un système distribué d'aide à la décision a été implanté afin d'assister le personnel du Centre des opérations dans le traitement des événements d'opérations antidrogues; pour l'interception de trafiquants de drogues violant l'espace aérien canadien, et ce en coordination avec divers services. Le but de ce système d'aide à la décision, appelé "*Commander's Advisory System for Airspace Protection* (CASAP)", est d'aider le personnel du Centre des opérations à décrire et partager l'information sur ce type d'incident, de développer des suites d'actions pertinentes, d'évaluer ces suites d'actions et de déterminer la plus appropriée. Un élément important de ce système est le module semi-automatisé d'aide à la décision pour la sélection de suites d'actions. Ce module a été développé afin d'aider le commandant à classer par priorité et à analyser les suites d'actions. Ce document présente CASAP et l'approche du module d'aide à la décision (aide multicritère à la décision). Le partage des responsabilités entre l'analyste multicritère, le décideur (le commandant) et l'ordinateur qui a été implanté dans ce module est discuté.

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Executive summary

Defence Research and Development Canada (DRDC) - Valcartier initiated a research activity aimed at investigating and developing advanced technologies, approaches and concepts to provide the 1CAD/CANR Air Operations Centre (AOC) Commander and his senior staff with advisory tools for planning, management and employment of air defence resources and capabilities. An advisor tool was designed to assist the AOC staff managing events and their related Courses Of Action (COAs), as well as prioritising these COAs according to different evaluation criteria. This command and control tool, called *Commander's Advisory System for Airspace Protection* (CASAP), was foremost developed to deal with events of counter-drug operations: to intercept drug smugglers violating the Canadian airspace, in co-ordination with different services and parties. Since the Commander needs to balance several conflicting and incommensurable criteria to make *"wise"* decisions in such a situation, Multiple Criteria Decision Aid models and procedures were deemed appropriate to deal with Canadian airspace protection decision-making situations.

This document briefly presents CASAP and the decision aid module approach used (Multiple Criteria Decision Aid (MCDA)). Finally, the implemented sharing of responsibilities between the MCDA analyst, the decision-maker (the Commander) and the computer is discussed.

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Sommaire

Recherche et développement pour la défense Canada (RDDC) - Valcartier a entrepris une activité de recherche visant à déterminer des approches et des concepts, et à mettre au point des technologies avancées à implanter dans des systèmes conseillers au commandant et au personnel du Centre des opérations aériennes de la Division 1CAD/CANR. Ces systèmes visent à apporter une aide au décideur dans les processus de planification, de gestion et d'utilisation des ressources et des capacités des forces aériennes. Dans le cadre de cette activité, les chercheurs du centre ont mis au point le prototype d'un outil conseiller (d'aide à la décision) permettant de soutenir le personnel du Centre des opérations aériennes à gérer des événements et leurs suites d'actions, ainsi que de ranger ces dernières par ordre de priorité. Cet outil de commandement et contrôle, appelé "*Commander's Advisory System for Airspace Protection* (CASAP)", a été mis au point spécifiquement pour traiter des événements lors d'opérations antidrogues; d'interception de trafiquants de drogues violant l'espace aérien canadien, et ce en coordination avec divers services. Dans ce type de situation, le commandant a besoin d'évaluer les différentes suites d'actions proposées selon plusieurs critères conflictuels et incommensurables afin de prendre la décision qui représente le meilleur compromis. Les modèles et procédures d'aide multicritère à la décision semblent être tout à fait appropriés aux situations décisionnelles dans le cadre de la protection de l'espace aérien canadien.

Ce document présente CASAP et l'approche du module d'aide à la décision (aide multicritère à la décision). Le partage des responsabilités entre l'analyste multicritère, le décideur (le commandant) et l'ordinateur qui a été implanté dans ce module est discuté.

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Acknowledgements

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1. Introduction

The 1 Canadian Air Division/Canadian NORAD Region (1 CAD/CANR) Air Operation Centre (AOC) is responsible for planning, conducting and monitoring operations. For routine operations, Command and Control (C2) decisions are taken through established doctrine, orders, and procedures. As contingency operations are introduced (crisis, contingency deployment or conflict) the AOC becomes the focal point for planning, directing, controlling, and monitoring assigned forces. An important element for either type of operation is the elaboration, mitigation and evaluation of different courses of actions (COAs) in order to respond to emergency situations.

A semi-automated distributed decision aid for the selection of COA was developed to assist the Commander in prioritising and analysing COA(s) for selection purposes. This module is based on a detailed investigation of how the Commander executes COAs' evaluation and selection processes. Since the Commander needs to balance several conflicting and incommensurable criteria to make "*wise*" decisions in such situations, Multiple Criteria Decision Aid (MCDA) models and procedures were deemed appropriate to deal with Canadian airspace protection decision-making situations.

Since such a module needs to have access to information from the situation and the different COAs provided by other AOC members, it has been integrated into a decision support system, called *Commander's Advisory System for Airspace Protection* (CASAP). CASAP enables the AOC team to describe and share information about such an incident, to develop pertinent COAs, evaluate them and determine which one is the most appropriate. This prototype was implemented to assist the Air Operation Centre (AOC) staff in dealing with events of counter-drug operations: to intercept drug smugglers violating the Canadian airspace, in co-ordination with different services and parties.

This technical note briefly presents CASAP and the decision aid system approach used (MCDA). Finally, the sharing of responsibilities between the MCDA analyst, the decision-maker (the Commander) and the computer, that has been implemented for this module is discussed.

2. CASAP

CASAP was developed to help the AOC team to describe and share information about a counter-drug incident, to develop pertinent COAs, to evaluate these COAs and to determine which one is the most appropriate. This DSS is based on a distributed asynchronous architecture, implemented with JAVA applets and servlets, and could be used through an Intranet browser (e.g. Netscape). The client side (event descriptor, COA descriptor, analyst and Commander) is implemented through applets, while the servlets are used on the server side to provide access to different databases and to evaluate the different COAs. The transportation of JAVA objects is performed through an http transportation layer (Figure 1).

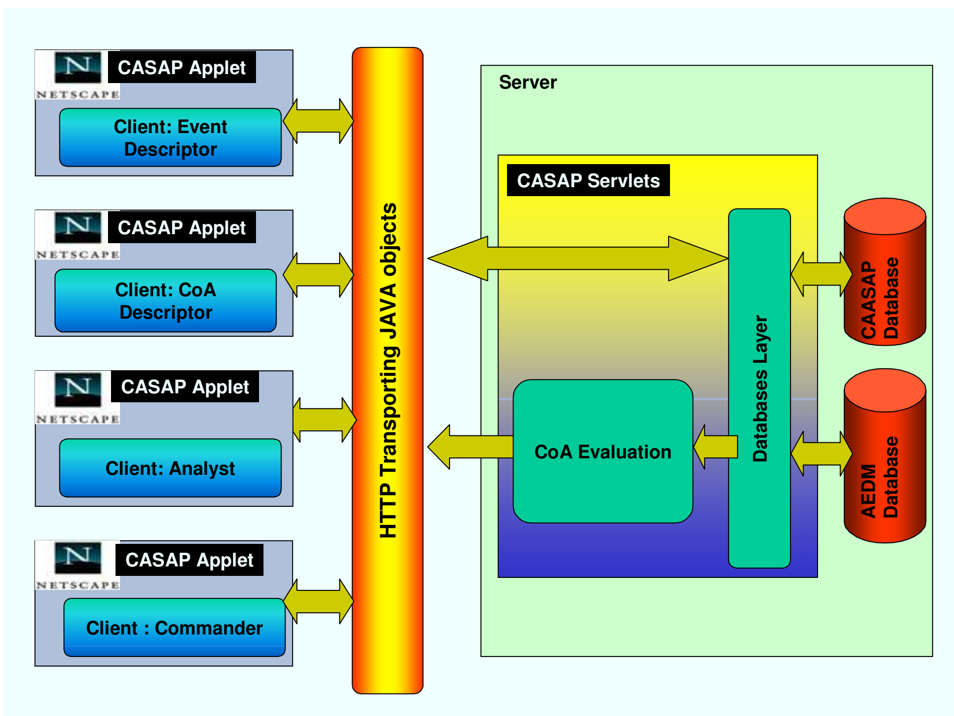

Figure 1. Physical architecture of CASAP

The four core functionalities of CASAP are the event description, the COA description, the criteria management and the COA selection. They are related to four different types of users: the people responsible for describing an event, those in charge of proposing COAs, the MCDA analyst and the person in charge of deciding the COA to be executed, the Commander [1].

The event description functionality allows a user to describe a counter-drug event and to share this information with other users. It includes a retrieval facility to search for similar past events and manage the event's database. The COA description functionality assists in the generation and description of COAs that might be executed to respond to the described event. It also includes the ability to retrieve and duplicate COAs from past or archived events. Once a satisfactory set of candidate COAs is generated, CASAP notifies the Commander. Then, the COA selection functionality can be used by the Commander for the selection process. A screening procedure (using a conjunctive method) is implemented to insure the quality of the COAs presented to the Commander. Then, criteria are selected and weighted, and each COA is evaluated according to each selected criterion. A multiple criteria decision analysis tool is provided to help the decision maker (DM) select the *"best"* COA. Moreover, the Commander can communicate with anyone logged on the CASAP system, either to announce the selection of a specific COA or to request additional candidate COAs. After the execution of a particular COA, a post-analysis facility can be used by the Commander to summarise and manage the lessons learned. The criteria management functionality is dedicated to set the parameters according to the MCDA procedure implemented. Although the current system was developed to deal specifically with counter-drug scenarios, the CASAP can easily be extended to other situations, by suitable adjustments to criteria and other parameters.

3. COA selection approach

The COA selection functionality has been developed based on a detailed investigation of how the AOC officers perform COAs evaluation and selection processes [2].

3.1 Decision-making process modelisation

A detailed investigation of how the experts perform the COA evaluation and selection activities included the analysis of Canadian military operation documents and operational checklists confronted to the knowledge acquisition sessions with the AOC senior staff members (the Decision-Makers). This analysis led to the identification of five factors to be considered while evaluating COAs for counter-drug scenarios in a peacetime context. The first aspect is related to the ability of a COA to adapt to various possible changes that may occur while implementing a COA (*flexibility* factor). The second one is the complexity related to the COA implementation (*complexity* factor). The third one is concerned by the ability to continue the (stay in) operation (*sustainability* factor). The two other factors are the optimality of the resources employment (*optimum use of resources* factor), and the risks of mission failure as well as the risks associated with the mission (*risk* factor).

Following the identification of these factors, knowledge acquisition sessions allowed the definition of sub-factors and heuristics to evaluate them. These sub-factors were specific aspects that the DMs are thinking about when evaluating a COA. This work was performed without any constraints for the DMs (e.g. without any dependency check between sub-factors, and confrontation).

The factors, sub-factors and their heuristics were partially validated with the staff of the FG/CANR HQ. All these factors and sub-factors are considered to select the most appropriate COA to a situation. However, each Commander would put different emphasis on different factors according to his own preferences related to his specific understanding of the situation and of the goal to achieve.

Since Commanders need to balance several conflicting and incommensurable aspects to make *"wise"* decisions, Multiple Criteria Decision Aid (MCDA) models and procedures were deemed to be appropriate to deal with Canadian airspace protection decision-making situations.

A MCDA analyst extracted criteria from the factors and sub-factors. In fact, 14 criteria were formulated (Table 1) and heuristics were proposed to evaluate the COAs according to each of them. These heuristics were based on the original ones, and the measurement scales used were conceived to preserve the natural DM's inputs (e.g. linguistic evaluation). These criteria are measured on scales ranging from cardinal deterministic, to ordinal, fuzzy, and probabilistic evaluations. The evaluation of the different COAs according to these criteria provides the basic information (data) to make a decision.

A Multiple Criteria Aggregation Procedure (MCAP) was then required to aggregate these data in order to prioritise and identify the best COA to overcome the threat. The MCDA analyst determined that PAMSSEM ("*Procédure d'Agrégation Multicritère de type Surclassement de Synthèse pour Évaluations Mixtes"*)[1] was suitable for the type of situation that our decision makers had to deal with [3]. PAMSSEM is a multicriteria aggregation procedure taking as input a multicriteria performance table[2] and producing a ranking of actions from the best one to the worst one, with eventually equality. The next section presents the user preference model on which this MCAP is based on.

Table 1. Criteria description

Factor	Criterion	Concerned with
Flexibility		
	C1: Covering Operational Tasks	the ability of a COA to adapt to possible changes in operational task which may occur during its implementation
	C2: Covering Mission's Possible Locations	the ability of a COA to adapt to possible changes in the predicted mission's locations which may occur during the implementation of a COA
	C3: Covering Enemy's COA	the ability of a COA to adapt in time to possible changes in the enemy's COA that may occur during the implementation
Complexity		
	C4: Operations Complexity	the COA implementation difficulties caused by its operational requirements
	C5: Logistics Complexity	the COA implementation difficulties caused by its logistics requirements
	C6: Command and Control Complexity	the COA implementation difficulties caused by command and control relationships and co-ordination requirements in operation
Sustainability		
	C7: Sustainability	the ability to continue (stay in) the operation as a function of the on-station time associated with the COA
Optimum use of resources		
	C8: Cost of Resources	the cost of the resources being used
Risk		
	C9: Impact of the Sensors Coverage Gap	the possibility of mission failure caused by the existence of radar and/or radio gaps
	C10: Military Personnel Loss	the likelihood of military personnel loss during the mission
	C11: Collateral Damage	the possibility of collateral damage (anything but the target) during the mission
	C12: Confrontation Risk	the possibility of mission failure due to confrontation
	C13: COA Equipment Reliability	the equipment reliability and the robustness of the COA
	C14: COA Personnel Effectiveness	the effectiveness of the personnel which may be jeopardised by fatigue, stress, etc. at any moment during the mission

3.2 Role of user preference in MCDA

The literature reviewed reveals many ways and theories about preferences articulation and modeling. For example, utility functions, valued functions, pair wise comparisons, tradeoffs, and discrimination thresholds could be used. This section presents the discrimination thresholds for preferences modeling according to a MCDA approach.

[1] Multiple Criteria Aggregation Procedure Based on the Outranking Synthesising Approach

2 A multicriteria performance table is a table containing, for each option, the value of evaluation according to each criterion.

Roy and Bouyssou [4] maintain that when comparing two options taking into account many criteria, a DM may be in one of the following situations:

- he/she is indifferent between a_i and a_k (denoted $a_i \sim a_k$),
- he/she strictly prefers a_i to a_k (denoted $a_i \succ a_k$),
- he/she weakly prefers a_i to a_k (hesitation between indifference and strict preference: denoted $a_i \succ^f a_k$), or
- he/she considers that a_i is incomparable to a_k (hesitation between $a_i \succ a_k$ and $a_k \succ a_i$, or the two options are *a priori* matchless: denoted $a_i \mathbf{?} a_k$).

The evaluation of an option with regard to a criterion is often uncertain and imprecise. Moreover, on top of these uncertainties and imprecision, the DM's preferences may involve some hesitations, doubts, indecision, etc. In order to take these behaviours into account, PAMSSEM introduces different types of parameters that represent the DM's preferences:

1. indifference threshold : represents the highest difference between the evaluations of two options according to a criterion *j* for which the DM is incapable of making a clear choice between these two options, given that everything is the same otherwise.
2. preference threshold : represents the smallest difference between the evaluations of two options according to the criterion *j* for which the DM is able to make a clear choice of one, given that everything is the same otherwise.
3. veto threshold : represents a limit of tolerance that the DM is willing to accept for any compensation. In other words, if the performance of an option a_k is higher than the performance of an option a_i through a criterion *j* by at least ν_j, then the DM may refuse to prefer a_i over a_k even if a_i is better evaluated than a_k through all the other criteria.
4. relative importance of each criterion : These coefficients represent the *"voting power"* the DM is willing to assign to each criterion.

Note that these thresholds introduce a very flexible way to model the nuances of the DM's preferences.

4. COA selection functionality

The COA selection functionality wants to provide to the DM appropriate decision aid tools. Since the Commander is the only one responsible for the COA selected, he always has the possibility to overwrite or to go over any automated procedure. The COA selection functionality is based on the MCDA approach and, accordingly, follows a certain sequence of actions before being able to propose a COA ranking. First, the thresholds and relative importance of each criterion must be set according to the DM's preferences. Then, each COA has to be evaluated according to each criterion. A minimum of performance is verified, and then the MCAP is applied to obtain a ranking of the COAs. Following the presentation of this ranking to the decision maker, different analysis procedures are made available.

Most of the time, MCDA tools are developed and used by MCDA analysts to help decision-makers structure and make their decisions. For our DSS approach, we wanted to provide the decision-makers with a tool that they could used directly. So we divided the activities into three groups: the ones that the MCDA analyst is responsible for (but that he might have to do with the help of the decision makers), the ones that the decision maker has to do for a specific situation and the ones that the computer is responsible to provide. The following subsections present this sharing of responsibilities that have been implemented between the humans (MCDA analyst and the Commander) and the computer.

4.1 MCDA analyst responsibility

Since the major challenge facing the implementation of any MCAP is the "*accurate*" assessment of the discrimination parameters (Indifference Thresholds, Strict Preference Thresholds, Veto Thresholds, COA Filtering Thresholds), it has been decided to give this responsibility to the MCDA analyst. This approach will solve the problem that end users may have general misunderstanding of the roles and meanings of these thresholds. The values of the thresholds are determined in a co-operative way with the MCDA analyst and the DM (in this case, the Commander or the person in charge of the AOC) [3]. When determined, the MCDA analyst must set the thresholds with the criteria management functions. He/she is also responsible for monitoring the validity of these parameters all the time.

4.2 Commander responsibility

The Commander is the decision maker, which is responsible for the decision made (the COA selected). Since the ranking proposed by the MCDA method depends on the importance that is given to each criteria, and that these importance are specific to each situation, the DM must set them very carefully each time. The way to determine the weights of criteria is not obvious, and the fact that there are 14 criteria makes it harder. A semi-automated method as been implemented to help the DM determine the weight for each criterion. This is done by asking him to rank them from the less important to the most important, and to determine how many times the most important criterion is more important than the less important.

Then, as needed, he puts as many graphically basic units between each two criteria to represent the difference of importance between them. This information is used by the computer to determine the relative importance of each criterion.

After considering the information related to the ranking proposed by the computer and using the different analysis tools offered to him, the Commander has to decide if one of the proposed COAs satisfied him/her or not. If he decides to select one of the COA, which can be the one proposed by the tool or not, he/she only have to select it, and if wanted, he/she can add any comments to give any precision on its decision. If the decision maker wants to have more COAs, he/she only has to push on the "Need more COAs" button, and the COAs editors will be notified.

Once the COA has been selected and executed, the Commander can see if this decision was the best one or not. In order to keep this precious knowledge, the prototype provide a post-execution comments facility. Then the Commander may specify any information that may be useful to future operations (this is used to learn from experience).

4.3 Computer responsibility

4.3.1 Determination of default values for the MCDA procedure

Users of decision aids face difficulties to set proper values for these parameters; in many situations, they may simply ignore these parameters. Roy and Bouyssou [4] maintain that it is better to set imperfect values than ignoring them. Based on this argument, default procedure for settings these thresholds have been implemented within CASAP [3]. The default values are variable, and depend on the type of event considered. So, when there is no value for these parameters, the computer determines default values for them automatically.

4.3.2 COA evaluation

The evaluation of each COA according to each criterion is realised automatically mostly with heuristics. Sometimes, these heuristics necessitate the contribution of the COA editor to provide specific evaluation aspects. There are specific screens used to ask the COA editor his/her own feeling about them. Sometimes, the heuristics needs information that are in a regular AF information systems. These are automatically retrieved from the appropriate information systems. In all these cases, the computer does whatever is needed to evaluate the COAs.

4.3.3 COA filtering

When having the evaluation of each COA for each criterion, the computer verifies if each evaluation is better than a certain level that has been set by the decision maker. The filtering functionality verifies if the "passing threshold" is respected for all criteria that have one. If a COA does not respect this threshold, then this COA is removed from the list of appropriate COAs.

4.3.4 Verification of COA dominance

The system verifies if there is a COA better than all the other according to all the criteria. The dominance verification facility verify if a COA is better of all other COAs on all criteria, no matter the value that can be assigned to the different thresholds. If a COA is better than all others, the computer presents directly this result to the Commander.

4.3.5 Determination of the relative importance of each criterion

Based on the information related to the importance of each criteria that has been provided by the decision maker, the computer automatically determine the relative importance of each criterion. The method implemented in the tool is based on the method of "Simos modifié" [5].

4.3.6 Comparison of COA (PAMSSEM)

The computer uses PAMSSEM, a multicriteria aggregation procedure taking as input a multicriteria performance table[3] to producing a ranking of actions from the best one to the worst one, with eventual equality. The Commander is provided with this ranking.

4.3.7 Analysis of the proposed ranking

As mentioned in subsection 4.2, the Commander has access to different analysis tools. These tools are a weight stability analysis tool, a threshold what-if analysis tool and an evaluation what-if analysis tool.

In the weight stability analysis tool, CASAP presents the impact of modifying the weights of different criteria on the ranking.

In the threshold what-if analysis tool, CASAP presents the effects of modifying criteria thresholds (preference, indifference or veto) on the ranking. The DM only has to specify which ones of the criteria he/she wants to modify and the tool presents what would be the resulted ranking with these new values. The presentation of the two different ranking results in a same screen will help the DM compare them and make appropriate decisions.

In the evaluation what-if analysis tool, CASAP presents the effects of having better/worst evaluations for one or many criteria evaluations on the ranking. The DM can change directly the value of some of the evaluations and see what would be the resulted ranking with these new values. Here again, the presentation of the two different ranking results in a same screen will help the DM compare them and make appropriate decisions.

3 A multicriteria performance table is a table containing, for each option, the value of evaluation according to each criterion.

5. Conclusion

A semi-automated distributed decision support for airspace protection has been developed based on the MCDA approach which appeared to be appropriate to deal with military strategic and operational decision-making situations. This document has presented the prototype that was developed to help AOC staff members to manage events and their related possible COA(s), and the Commander to prioritise and analyse COA(s) for selection purposes. It describes the decision aid module approach used (MCDA), and presents the assignation of responsibility between the MCDA analyst, the Commander and the computer.

The challenge when developing a decision aid system is to determine who, between the human and the system, should do what. Who is the best to do what in the process of making a decision? The MCDA approach facilitates this task by providing a sequential structure of activities that have to be realised to obtain a recommended action. The sharing of responsibilities between the MCDA analyst, the decision maker (the Commander) and the computer proposed in this work is not perfect, but wants to be a first try in developing a human-system decision-support system for military operations decisions. Furthermore, the computer always has the role of replacing the decision maker when he/she is not providing the information that are expected from him/her. For example, the system will determine default values for the thresholds when he/she realised that the DM did not determine them. However, since the Commander has the responsibility to decide, he/she always can decide to not consider the system proposition, as, in real-world life, he always can decide to not consider any of his/her staff propositions or advices.

An aspect that could improve this tool would be the implementation of explanation, justification and argumentation capabilities to provide a more interactive way of challenging the system results. We think that this aspect would improve the integration of such DSS into an operational world.

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List of symbols/abbreviations/acronyms/initialisms

1CAD/CANR	1 Canadian Air Division/Canadian NORAD Region
AOC	Operation Centre
C2	Command and Control
CASAP	Commander's Advisory System for Airspace Protection
COA	Course Of Action
DM	Decision Maker
DND	Department of National Defence
DRDC	Defence Research and Development Canada
DSS	Decision Support System
MCAP	Multiple Criteria Aggregation Procedure
MCDA	Multiple Criteria Decision Aid
PAMSSEM	Procédure d'agrégation multicritère de type surclassement de synthèse pour évaluations mixtes
RDDC	Recherche et développement pour la défense Canada

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A distributed Decision Support System (DSS) was implemented to assist the Air Operation Centre (AOC) staff in dealing with events of counter-drug operations: to intercept drug smugglers violating the Canadian airspace, in co-ordination with different services and parties. This DSS, called Commander's Advisory System for Airspace Protection (CASAP), aims at helping the AOC team to describe and share information about such an incident, developing pertinent Courses Of Action (COAs), evaluating these COAs and determining which one is most appropriate. An important element of this system is a semi-automated decision aid module for the selection of COAs. This module was developed to assist the Commander in prioritising and analysing COAs. This document briefly presents CASAP and the decision aid module approach used (Multiple Criteria Decision Aid (MCDA)). Finally, the implemented sharing of responsibilities between the MCDA analyst, the decision-maker (the Commander) and the computer is discussed.

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

Decision aid

Decision support

Decision support system

Estimate Process

Course of actions

COA

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