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COA ADVISORY SYSTEM BASED ON THE MULTIPLE CRITERIA DECISION ANALYSIS

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ABSTRACT

An important element of military operations is the elaboration, mitigation and evaluation of different Courses of Actions (CoAs) in order to overcome emergency situations. In this kind of decision-making situation, it is important to consider several criteria to evaluate the various CoAs, and to perform analyses to compare and rank the CoAs according to their ability to meet the selected criteria. It is often necessary to balance the importance of these criteria accordingly to the decision-maker's (Commander) values. The Defence Research Establishment Valcartier has developed an advisory tool prototype, which could be used to describe an airspace violation incident, to describe and evaluate different CoAs, and to perform decision analysis in order to determine the most appropriate CoA. The evaluation of the CoAs is accomplished within a multiple criteria decision aid framework. In this technical note, we briefly report the development of the Commander's Advisory System for the Airspace Protection (CASAP).

RÉSUMÉ

Le personnel du poste de Commandement est souvent appelé à générer et évaluer plusieurs suites d'actions et des plans de contingence pour intervenir dans des situations d'urgence. Dans de telles situations, le processus d'évaluation des suites d'actions implique la prise en compte de plusieurs critères, souvent conflictuels et incommensurables, pour évaluer et comparer les différentes suites d'actions. Cette évaluation exige souvent la pondération de l'importance des critères en fonction des valeurs et des préférences du décideur (Commandant). Le Centre de recherches pour la défense Valcartier a développé un prototype d'un système d'aide à la décision permettant de décrire un incident de violation de l'espace aérien, de décrire et d'évaluer les différentes suites d'actions proposées, et de déterminer la plus appropriée à la situation. L'évaluation des suites d'actions et l'analyse de la décision sont réalisées dans le cadre d'une méthodologie d'aide multicritère à la décision. Cette note technique rapporte brièvement les développements réalisés pour la mise au point du "Commander's Advisory System for the Airspace Protection" (CASAP).

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EXECUTIVE SUMMARY

Within 1 CAD/CANR, the Air Operation Centre (AOC) is responsible for the day-to-day air force operations. For routine operations, command and control decisions are effected 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 Action (CoAs) in order to respond to the emergency situations. During such situations, AOC staff members work under stress conditions, and have to process a large amount of information within a short time cycle. In fact, time constrains the process to extensively assess the situation, generate wide-range of CoAs, and intensively evaluate them according to significant point-of-views, before selecting and executing the "best" CoA representing the best possible compromise according to the criteria. Further, key experts might be outside the Command post during this crucial time.

The Defence Research Establishment Valcartier has undergone research activities to investigate ways to help the AOC Commander and staff managing airspace violation and their related CoAs. In fact, It was possible to develop an advisory tool prototype, which allow to describe and manage an airspace violation incident, and its related CoAs. It helps the staff evaluating these CoAs according to selected criteria, and then determines the most appropriate one. The evaluation of the CoAs and the prioritisation analysis is accomplished within a multiple criteria decision aid framework. The system architecture allows the different users to login in a distributed and unsynchronised manner. In fact, the prototype uses a distributed architecture, and is implemented with JAVA applets and servlets. It could be used through an Intranet browser like Netscape. In this technical note, we briefly report the development of the Commander's Advisory System for the Airspace Protection (CASAP). The original version of this note was accepted at the International Conference on Advances in Intelligent Systems: Theory and Applications, holding in Canberra, Australia, in February 2000.

LIST OF ACRONYMS

1 CAD	1 Canadian Air Division
1 CAD/CANR	1 Canadian Air Division/Canadian NORAD Region
AOC	Air Operation Centre
C2	Command and Control
CANR	Canadian NORAD Region
CAP	Canadian Airspace Protection
CASAP	Commander's Advisory System for Airspace Protection
CoA	Course of Action
DM	Decision-Maker
DSS	Decision Support System
DMS	Decision-Making Situation
DREV	Defence Research Establishment Valcartier
MCAP	Multiple Criteria Aggregation Procedure
MCDA	Multiple Criteria Decision Aid
NORAD	North American Airspace Defence
OODA	Object-Orient-Decid-Act
PAMSSEM	Procédure d'Agrégation Multicritère de type Surclassement de Synthèse pour Évaluations Mixtes

1.0 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 effected 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 the emergency situations.

In order to develop a semi-automated distributed decision support for airspace protection, researchers from Defence Research Establishment Valcartier (DREV) worked previously with the Commander and his senior staff at the former Fighter Group/CANR headquarters. This effort was aimed to structure the decision-making situation (DMS) and identify key factors to evaluate different CoAs. Since, 1997 this work has continued, but many of the factors and criteria needed to be re-validated with the stand-up of the new operational level 1 CAD/CANR headquarters. Commanders need to balance several objectives to make *"wise"* decisions, Multiple Criteria Decision Analysis (MCDA) appeared to be appropriate to deal with military strategic and operational DMS.

This paper briefly describes the knowledge modelling and engineering processes to formulate different evaluation criteria, as well as the relevance of the MCDA methodology for developing a decision support system (DSS) called *Commander's Advisory System for Airspace Protection* (CASAP). This prototype aims 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. The functional architecture of the CASAP is also presented.

This work was conducted at DREV in conjunction with the Centre for Operational Research and Analysis at 1CAD/CANR during the period of January 1997 to September 1999 within the Work Unit 3ae12: *Commander's COA Advisory Systems Demonstrators* of project 3ae: *Commander's CoA Advisory Systems*. The original version of this paper was accepted at the International Conference on Advances in Intelligent Systems: Theory and Applications, holding in Canberra, Australia, in February 2000.

2.0 KNOWLEDGE STRUCTURING OF THE DECISION-MAKING SITUATION

Within 1 CAD/CANR, AOC is responsible for day-to-day air force operations monitoring and control. For routine operations, C2 decisions are effected through established doctrine, orders, and procedures [Ref. 1]. In this situation, the C2 process, modelled by the Object-Orient-Decide-Act (OODA) loop (Fig. 1), particularly the D portion, gets compressed since there are pre-defined operation orders, and more often default CoA decided. As contingency operations are introduced (crisis, contingency deployment or conflict), the AOC becomes the focal point for planning, directing, controlling, and monitoring assigned forces. When an airspace violation event does not fit into a routine operation, it is considered as an immediate operational contingency. In that situation, the AOC is activated and has to complete all the activities in the OODA loop.

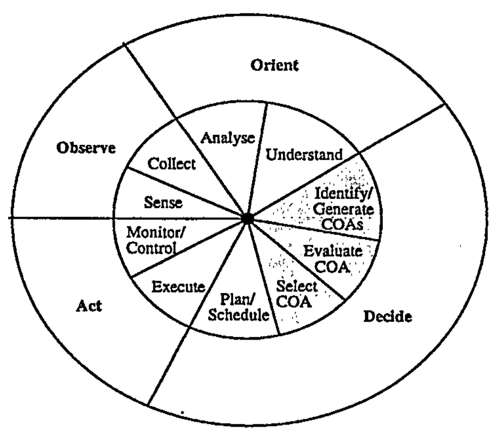

FIGURE 1 - The Observe, Orient, Decide and Act (OODA) loop for Command and Control

During such stressful situations, time constrains the process to extensively assess the situation, generate wide-range of CoAs, and to intensively evaluate them according to significant point-of-views, before selecting and executing the *"best"* CoA: the one achieving the best compromise among all the evaluation criteria. Moreover, it might be impossible to have access to the experience of resources that are not inside the AOC at that specific time. That is why a CoA advisory tool would greatly assist the AOC staff in ensuring that the CoA development and analysis process is correctly performed, and the selection of a suitable CoA is accomplished in a timely manner.

In order to develop a DSS to assist the AOC Commander and staff, many knowledge acquisition and modelling sessions were organised with the different stakeholders. An initial inquiry (see Scott et al. [Ref. 2]) was performed to better understand the operational context in which such DSS would operate. It appeared that, for contingency planning, the processes of generation and evaluation of possible CoAs involved a team approach. Presently, 1 CAD/CANR has a permanent immediate action team(IAT) in place, consisting of subject-matter experts, with a team leader responsible to present recommended CoAs to the Commander for selection and validation.

The second step of the knowledge structuring process involved a detailed investigation of how the experts perform these activities. This investigation included the analysis of Canadian military operation documents (ex. [Ref. 1,3,4]) and operational checklists confronted to the knowledge acquisition sessions with the AOC senior staff members (the decision-makers (DMs)). 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 with the DMs 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 done 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. During a more formal knowledge formulation step, dependencies between sub-factors were identified. It was then decided to rethink the factors and sub-factors according to the MCDA methodology. Accordingly, each of the factors was decomposed into one or many evaluation criteria. In fact, 14 criteria were formulated (see Table 1) and heuristics were proposed to evaluate the CoAs according to each one 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.

TABLE I

A summary of the 14 criteria [Ref. 5]

Factor	Criterion	Optimisation	Scale	Evaluation
Flexibility				
C1:	Covering Operational Tasks	Maximise	Cardinal on [0,1]	Crisp, Deterministic, Continuous
C2:	Covering Mission's locations	Maximise	Cardinal on [0,1]	Crisp, Probabilistic, Continuous
C3:	Covering Enemy's CoA	Maximise	Cardinal on [0,1]	Crisp, Probabilistic, Continuous
Complexity				
C4:	Operations Complexity	Minimise	Ordinal, 5 echelons	Crisp, Deterministic, Discrete
C5:	Logistics Complexity	Minimise	Ordinal, 5 echelons	Crisp, Deterministic, Discrete
C6:	C&C Complexity	Minimise	Ordinal, 5 echelons	Distribution, Discrete
Sustainability				
C7:	Sustainability	Maximise	Cardinal, $\mathbf{R}^+$	Crisp, Deterministic, Continuous
Cost of resources				
C8:	Cost of Resources	Minimise	Cardinal, $\mathbf{R}^+$	Crisp, Deterministic, Continuous
Risk				
C9:	Impact of Sensors Coverage Gap	Minimise	Ordinal, 3 echelons	Distribution, Discrete
C10:	Military personnel loss	Minimise	Ordinal, 7 echelons	Crisp, Probabilistic, Discrete
C11:	Collateral damage	Minimise	Ordinal, 7 echelons	Crisp, Deterministic, Discrete
C12:	Confrontation risk	Minimise	Ordinal, 7 echelons	Crisp, Probabilistic, Discrete
C13:	Equipment reliability	Maximise	Cardinal on [0,1]	Crisp, Probabilistic, Discrete
C14:	Personnel effectiveness	Maximise	Ordinal, 5 echelons	Fuzzy, Distribution, Continuous

Even if the criteria had been developed based on the information provided by the DMs, a validation process still needs to be done, in order to verify the coherence of the family of criteria. This involves the DMs to verify that these criteria are exhaustive, cohesive and non-redundant. As a matter of fact, these criteria were introduced to various planning staff in the 1 CAD/CANR headquarters. Further validation phases will be performed among other ways by using the CASAP. We uphold that the prototype will offer a visual way to present the evaluation criteria and facilitate the validation process. It is important to mention the difficulty of having working sessions with these DMs due to their occupations.

3.0 MULTIPLE CRITERIA DECISION ANALYSIS METHODOLOGY

Multiple Criteria Decision Analysis (MCDA) methodology aims to help the DM handle semi-structured and multidimensional decision problems with multiple criteria, where the components are transitional and the required information insufficient [Ref. 6]. Within the paradigm of the classical operational research, a decision problem is modelled by an objective function (f) to be optimised over a set of feasible solutions (X); it is the essence of classical mathematical programming. Within, the MCDA perspective, the idea of the *optimal solution* is replaced by the concept of *satisfactory alternative,* which realises the best possible compromise for the DM considering all the conflicting and non-commensurable evaluation criteria. This change was the beginning of the development of many multiple criteria decision aid methods.

Let **A** be the set of the CoAs, **A** = $\{a_1, a_2, \ldots, a_i, \ldots, a_m\}$, and **F** a coherent family of criteria, **F**=$\{C_1, C_2, \ldots, C_j, \ldots, C_n\}$. The value of the i^{th} CoA evaluation according to the j^{th} criterion is denoted e_{ij}. The evaluation of all the CoAs according to the set of criteria produces the multiple criteria performance table **E** (see table II).

TABLE II

Multiple Criteria Performance Matrix **E**

		Criteria (1...n)				
		C_1	...	C_j	...	C_n
CoAs (1...m)	a_1	e_{11}	...	e_{1j}	...	e_{1n}
	:	:	:	:	:	:
	a_i	e_{i1}	...	e_{ij}	...	e_{in}
	:	:	:	:	:	:
	a_m	e_{m1}	...	e_{mj}	...	e_{mn}

Within the MCDA framework, the decision-aid process involves an extensive effort to articulate and model the DM's preferences. Then, the DM's preferences and the evaluations contained in **E** should be aggregated in order to recommend the *"best decision"* accordingly with the DM's values. During the last three decades, the MCDA discipline has undergone significant development, which gives rise to several methods and procedures. The review of the literature suggests that the different known discrete MCAPs are based on different operational approaches [Ref. 7]. The single criterion synthesising approach, for example, seeks to build an aggregation function V to represent the global score of a CoA a_i by a single synthesising criterion $C(a_i)$ obtained from the scores with regard to criteria $C_1,...,C_n$ by $V(a_i)=f[C_1(a_i),\ldots,C_n(a_i)]$ (see [Ref. 8]). The outranking synthesising approach, for instance, seeks to establish an outranking relation between each pair of CoAs; $a_i\mathbf{S}a_k$: a_i outranks a_k = a_i "is at least as good as" a_k (see [Ref. 9, 10]). Instead of computing a score for each CoA a_i, it computes $V(a_i,a_k)$ for each pair of CoAs $(a_i,a_k)\in\mathbf{A}\times\mathbf{A}$. The outcome of a MCAP could be a total/partial pre-order of the alternatives, a sorting into categories, a choice, etc.

Further to a comparison study of various discrete aggregation procedures [Ref. 11], the procedure PAMSSEM (*"Procédure d'Agrégation Multicritère de type Surclassement de Synthèse pour Évaluations Mixtes"*)[1] was considered appropriate to be implemented in CASAP [Ref. 12] to aggregate the evaluations obtained according to the 14 heterogeneous criteria. In fact, PAMSSEM was designed to deal with mixed and missing evaluations. The evaluations can be crisp quantities, discrete/continuous random variables (with mass or density probability functions), linguistic or fuzzy numbers (membership functions). PAMSSEM also deals with missing evaluations that could be the result of lack of knowledge, forgetfulness or inappropriateness. It produces either a partial or a total pre-order of the alternatives. It offers enough flexibility to consider the DM's preferences and to control the compensations. The original version of PAMSSEM was developed by Martel *et al.* [Ref. 13].

During this project, different add-ins were developed with PAMSSEM. A graphical and intuitive tool was designed for weighting the criteria. A stability interval analysis was also developed for the relative importance coefficients. Moreover, two different heuristics were designed to help performing "what-if" analyses on PAMSSEM's parameters, as well as on the evaluations. For more details about PAMSSEM and its add-ins, the reader is refereed to DREV-Report 1999-215 [Ref. 12].

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

4.0 COA ADVISORY SYSTEM

The CASAP was originally developed to deal with events of counter-drug operations. It aims to help the AOC team to describe and share information about such an incident, to develop pertinent CoAs, to evaluate these CoAs and to determine which one is 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 like Netscape (see fig. 2).

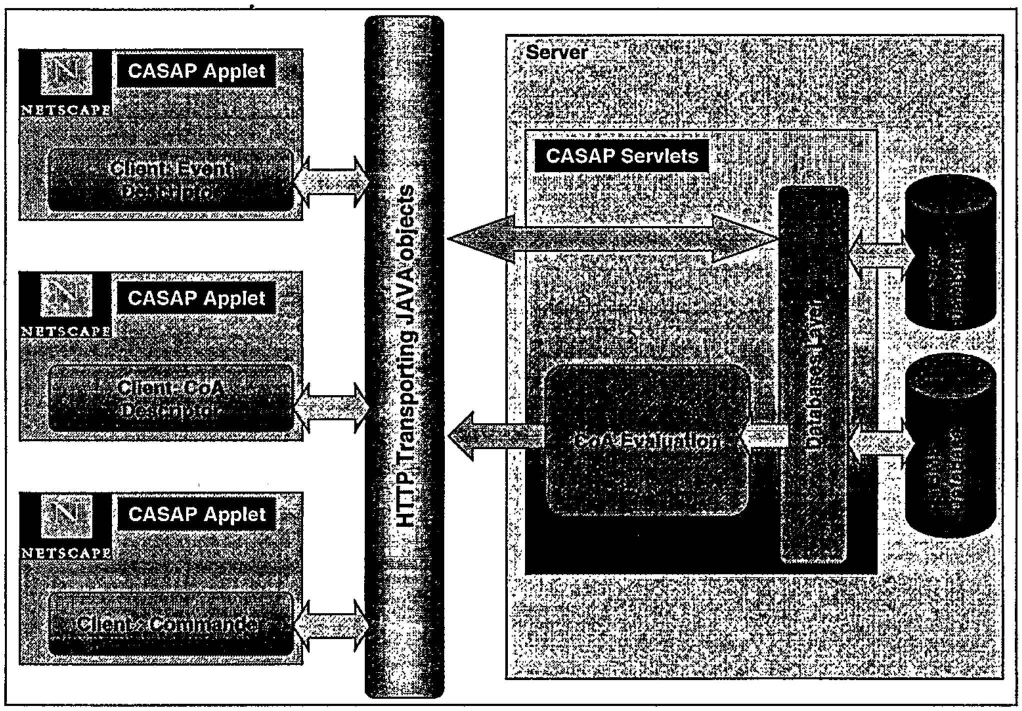

FIGURE 2 - CASAP distributed architecture

The functional architecture of CASAP encloses six modules (Fig. 3). A first module allows a user to describe a counter-drug event and to share this information with other users. It includes a retrieval facility to search out similar past events and manage the event's database. A second module assists in the generation and description of CoAs that might be executed to respond to the described event. This module includes the ability to retrieve and duplicate CoAs from past or archived events.

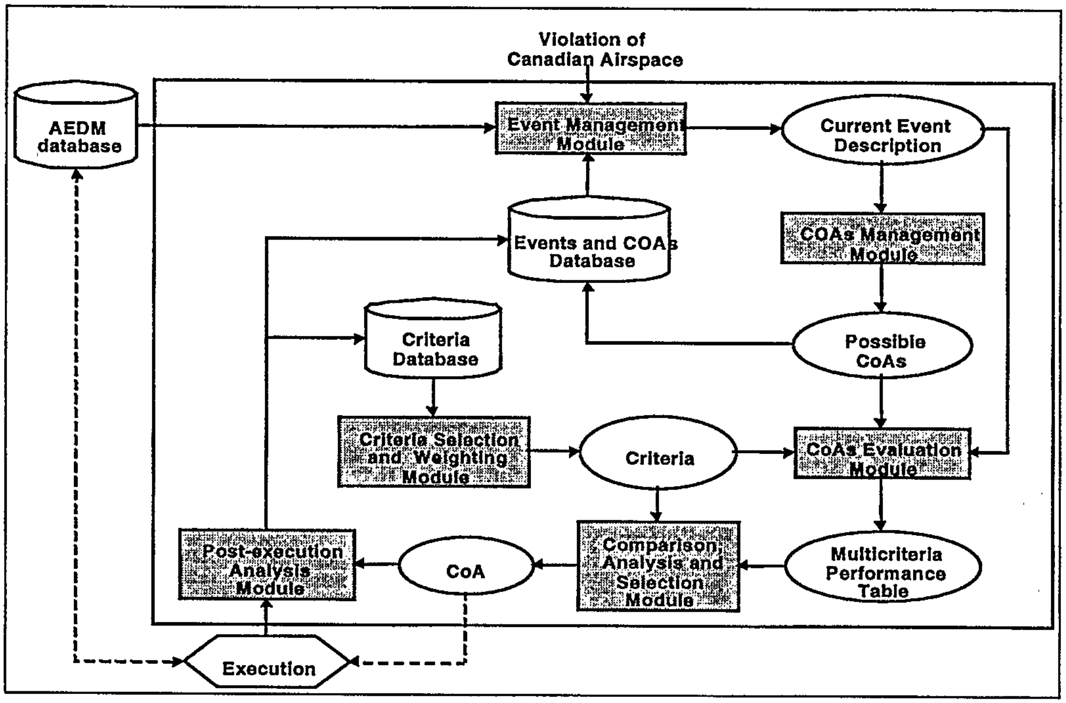

FIGURE 3 - Prototype modules

Once a satisfactory set of candidate CoAs is generated, CASAP notifies the Commander. Then the selection process begins. To help in this process, a third module evaluates each CoA according to each selected criterion. These criteria are selected and weighted using the fourth module. A screening procedure (using a conjunctive method) is implemented to insure the quality of the CoAs presented to the Commander. The fifth module makes use of the multiple criteria decision analysis tools that were previously described to help the DM selecting 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 module can be used to summarise and manage lessons learned. Although the present 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.

5.0 DISCUSSION / CONCLUSION

To produce an advisory tool, we had to propose models to formally represent an event as well as a CoA. The definition of such models was possible through a series of knowledge acquisition sessions. The event model encompasses operational information, useful for the advisory tool requirements (ex. type of enemy aircraft, enemy intention, etc.), as well as contextual information (ex. political and social considerations, etc.). Even if the event model would have been a lot simpler without this contextual information, it appeared that this kind of information is crucial for the operators in the CoAs generation process. Furthermore, such a model can be used to sort out similar cases that may have happened in the past. Interviewed AOC staff considers this latter feature of comparing with similar previous cases as an appreciated capability of any CoA advisory tool.

Since the evaluations of the CoAs according to the different criteria might include uncertainty, ambiguity, fuzziness, and subjectivity, several analysis tools were developed to help minimise the risk component introduced during the evaluation process. These tools allow to answer the following question: *"What could happen to the actual ranking if one or more evaluations of one or many CoAs change, or if the preferences and/or criteria relative importance coefficients are modified?"*.

An aspect that could improve our tool would be the implementation of an explanation capability to provide explanations of the results adapted to the user (his background/experience/knowledge/preference/etc.), and to the decisional context (time available, etc.). This aspect would improve the integration of such a DSS to an operational world.

To be fully efficient, a CoA advisory system would need to interact with many other information systems as shown in figure 4. This may include receiving information related to the event (commonly referred to as situational awareness), and to the availability of resources. The system could send the selected CoA to a scheduling system for developing tasking orders. The mission could be monitored by the AOC during its execution, and feedback could be gathered for post-execution analysis.

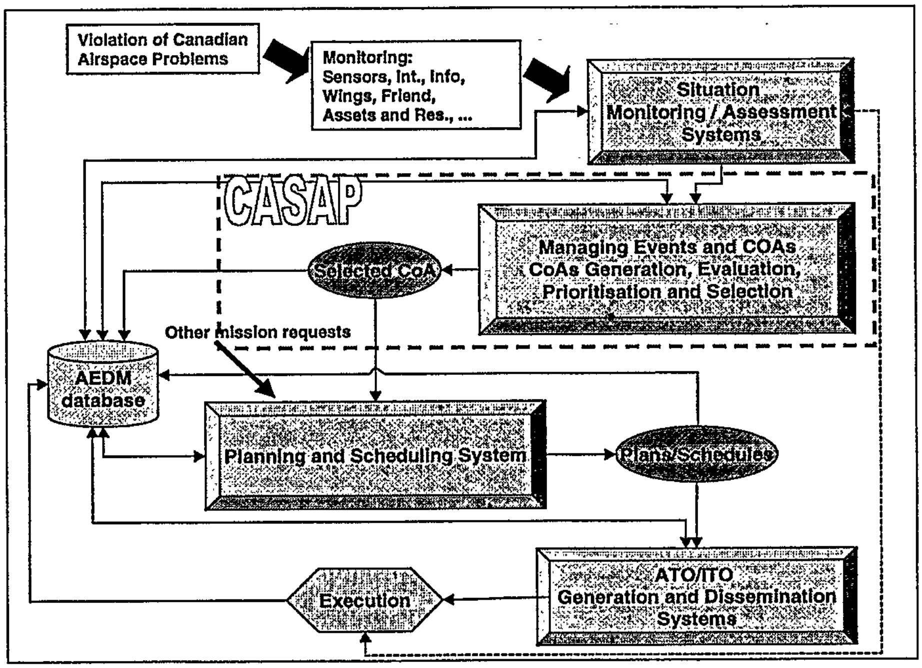

FIGURE 4 - CASAP Integration to a global C2IS

This paper has briefly presented the processes used to develop an advisory system for the evaluation of CoAs in a context of Canadian airspace protection. Even if the prototype is still in the development phase, we have made significant steps toward developing a decision support system meeting the needs of the AOC staff members. Furthermore, we think that this type of tool could be used for other types of air force decision situations such as hijacking and disaster response (ex. major air crash). The same methodology would also be applicable to a Strategic Plans cell that is activated when longer term issues relating to a contingency operation arise as a result of a Commander's guidance requiring option analyses and CoAs generated. Now, we think that we better understand the challenges of knowledge modelling and engineering, and we consider that combining the MCDA methodology and information technologies was successful to implement a DSS.

6.0 ACKNOWLEDGMENTS

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ABSTRACT

An important element of military operations is the elaboration, mitigation and evaluation of different Courses of Actions (CoAs) in order to overcome emergency situations. In this kind of decision-making situation, it is important to consider several criteria to evaluate the various CoAs, and to perform analyses to compare and rank the CoAs according to their ability to meet the selected criteria. It is often necessary to balance the importance of these criteria accordingly to the decision-maker's (Commander) values. The Defence Research Establishment Valcartier has developed an advisory tool prototype, which could be used to describe an airspace violation incident, to describe and evaluate different CoAs, and to perform decision analysis in order to determine the most appropriate CoA. The evaluation of the CoAs is accomplished within a multiple criteria decision aid framework. In this technical note, we briefly report the development of the Commander's Advisory System for the Airspace Protection (CASAP).

RÉSUMÉ

Le personnel du poste de Commandement est souvent appelé à générer et évaluer plusieurs suites d'actions et des plans de contingence pour intervenir dans des situations d'urgence. Dans de telles situations, le processus d'évaluation des suites d'actions implique la prise en compte de plusieurs critères, souvent conflictuels et incommensurables, pour évaluer et comparer les différentes suites d'actions. Cette évaluation exige souvent la pondération de l'importance des critères en fonction des valeurs et des préférences du décideur (Commandant). Le Centre de recherches pour la défense Valcartier a développé un prototype d'un système d'aide à la décision permettant de décrire un incident de violation de l'espace aérien, de décrire et d'évaluer les différentes suites d'actions proposées, et de déterminer la plus appropriée à la situation. L'évaluation des suites d'actions et l'analyse de la décision sont réalisées dans le cadre d'une méthodologie d'aide multicritère à la décision. Cette note technique rapporte brièvement les développements réalisés pour la mise au point du "Commander's Advisory System for the Airspace Protection" (CASAP).

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