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Holistic approach and framework for the building of knowledge-based situation analysis support systems

J. Roy
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Defence R&D Canada – Valcartier
Technical Report
DRDC Valcartier TR 2005-420
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Abstract

Over the years, situation awareness has emerged as an important concept supporting dynamic human decision-making in both military and public security environments, while situation analysis is defined as the process that provides and maintains a state of situation awareness for decision makers. Information fusion is a key enabler to meeting the demanding requirements of situation analysis in future command and control and intelligence support systems. Combining elements of information fusion and knowledge-based systems, this report presents a holistic approach and framework, including some recommended high-level steps, for the overall development and evaluation of any knowledge-based situation analysis support system. The report provides a comprehensive description of the approach, thereby contributing to the development of a foundational R&D framework for two projects that are just starting at Defence R&D Canada. Emphasis is given to the knowledge-centric aspects of the approach. Topics being discussed include cognitive, software, knowledge and ontological engineering. Subject matter experts, situation analysis processing nodes and processing trees, a priori supporting knowledge, system architecture issues, evaluation in laboratory testbeds using modeling and simulation, field demonstrations and experiments, and expert system development are other aspects being discussed in the report.

Résumé

Au fil des ans, l'éveil situationnel a émergé en tant que concept important en soutien à la prise de décision dynamique par des humains dans les milieux militaires et de la sécurité publique, alors que l'analyse de la situation est définie comme étant le processus qui fournit et maintient un état d'éveil situationnel pour les preneurs de décisions. La fusion d'information constitue un habilitant clé pour répondre aux besoins exigeants de l'analyse de la situation dans les systèmes futurs de soutien au commandement et contrôle et au renseignement. Combinant des éléments de la fusion d'information et des systèmes à base de connaissance, ce rapport présente une approche et un cadre holistiques, incluant des étapes recommandées de haut niveau pour le développement global et l'évaluation de tout système de soutien à l'analyse de la situation basé sur la connaissance. Le rapport fournit une description d'ensemble de l'approche, contribuant ainsi à la mise en place d'un cadre de base de R et D pour deux projets qui sont entrepris en ce moment à R et D pour la défense Canada. L'accent est mis sur les aspects de l'approche qui sont centrés sur la connaissance. Les sujets discutés incluent l'ingénierie cognitive, logicielle, de la connaissance et des ontologies. Les experts du domaine, les nœuds de traitement et les arbres de traitement de l'analyse de la situation, la connaissance a priori de soutien, les aspects d'architecture de système, l'évaluation sur bancs d'essais en laboratoire utilisant la modélisation et la simulation, les démonstrations et expériences sur le terrain, et le développement de systèmes experts sont d'autres points discutés dans ce rapport.

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Executive summary

Holistic approach and framework for the building of knowledge-based situation analysis support systems

Roy, J.; DRDC Valcartier TR 2005-420; Defence R&D Canada – Valcartier; January 2007.

Over the years, situation awareness has emerged as an important concept supporting dynamic human decision-making in both military and public security environments, while situation analysis is defined as the process that provides and maintains a state of situation awareness for the decision makers. Information fusion is a key enabler to meeting the demanding requirements of situation analysis in future command and control (C2) and intelligence support systems.

When adopting a knowledge-centric view of situation analysis, a corresponding well-structured development process needs to be defined and followed in order to build appropriate knowledge-based situation analysis support systems (SASSs). Combining elements of information fusion and knowledge-based systems, this report presents a holistic approach and framework, including some recommended high-level steps, for the overall development and evaluation of any knowledge-based SASS. Emphasis is given to the knowledge-centric aspects of the approach.

The report doesn't present "solutions" or findings and results of completed activities. The intent is more to provide a comprehensive description of a suitable development approach, in order to contribute to the development of a foundational R&D framework for two projects that are just starting under the Applied Research Program (ARP) at Defence R&D Canada: SATAC (Situation Analysis for the Tactical Army Commander), and CKE-4-MDA (Collaborative Knowledge Exploitation for Maritime Domain Awareness). Aspects being discussed include cognitive, software, knowledge and ontological engineering. Subject matter experts, situation analysis processing nodes and processing trees, a priori supporting knowledge, system architecture issues, evaluation in laboratory testbeds using modeling and simulation, field demonstrations and experiments, and expert system development are other topics being discussed in the report.

Situation analysis and information fusion (SAIF) play a critical role in the C2 and intelligence processes, and have already received significant attention for military applications. Numerous ongoing projects of the Department of National Defence (DND) and also at Defence R&D Canada possess an important SAIF component. However, despite the importance given to SAIF in many DND strategic documents and projects, the current systems and the associated technology often fail to meet the demanding requirements of the operational decision makers; major science and technology advances are required to really achieve the full potential of the related enabling technologies and to best serve the operational communities. The effort reported here constitutes one step in this direction; it contributes to the establishment of a solid basis on which a long-term R&D program should be built.

This report only provides an initial overview of the many issues arising from the holistic approach and framework; one needs to dig deeper into these issues to really embrace this approach and develop appropriate support systems meeting the demanding requirements of the operational communities. Hence, R&D activities have been and are still currently being conducted to further

investigate knowledge representation concepts, paradigms and techniques, and reasoning processes, methods and systems for use in knowledge-based SAIF support systems. Adopting a knowledge-centric view of SAIF and the approach presented in this report requires that knowledge (i.e., expertise) is eventually acquired from the subject matter experts (SMEs) of the different military and public security application domains. In this regard, knowledge and ontological engineering techniques have been and are still being investigated at the moment. Knowledge acquisition and validation sessions with SMEs are about to be conducted.

Sommaire

Holistic approach and framework for the building of knowledge-based situation analysis support systems

Roy, J.; DRDC Valcartier TR 2005-420; R et D pour la défense Canada – Valcartier; janvierJanuary 2007.

Au fil des ans, l'éveil situationnel a émergé en tant que concept important en soutien à la prise de décision dynamique par des humains dans les milieux militaires et de la sécurité publique, alors que l'analyse de la situation est définie comme étant le processus qui fournit et maintient un état d'éveil situationnel pour les preneurs de décisions. La fusion d'information constitue un habilitant clé pour répondre aux besoins exigeants de l'analyse de la situation dans les systèmes futurs de soutien au commandement et contrôle (C2) et au renseignement.

Lorsqu'on adopte une vue de l'analyse de la situation basée sur la connaissance, un processus de développement bien structuré correspondant doit être défini et suivi pour construire des systèmes appropriés de soutien à l'analyse de la situation (SSAS) basés sur la connaissance. Combinant des éléments de la fusion d'information et des systèmes à base de connaissance, ce rapport présente une approche et un cadre holistiques, incluant des étapes recommandées de haut niveau, pour le développement global et l'évaluation de tout SSAS basé sur la connaissance. L'accent est mis sur les aspects de l'approche qui sont centrés sur la connaissance.

Le rapport ne présente pas de "solutions" ou de découvertes et résultats d'activités complétées. L'intention est plutôt de fournir une description d'ensemble d'une approche appropriée de développement, dans le but de contribuer à la mise en place d'un cadre de base de R et D pour deux projets qui sont entrepris en ce moment dans le cadre du programme de recherches appliquées (PRA) à R et D pour la défense Canada: ASCAT (Analyse de la situation pour le commandant d'armée tactique), et ECCESDM (Exploitation collaborative de la connaissance pour l'éveil situationnel du domaine maritime). Les aspects discutés incluent l'ingénierie cognitive, logicielle, de la connaissance et des ontologies. Les experts du domaine, les nœuds de traitement et les arbres de traitement de l'analyse de la situation, la connaissance a priori de soutien, les aspects d'architecture de système, l'évaluation sur bancs d'essais en laboratoire utilisant la modélisation et la simulation, les démonstrations et expériences sur le terrain, et le développement de systèmes experts sont d'autres sujets discutés dans ce rapport.

L'analyse de la situation et la fusion d'information (ASFI) ont un rôle critique à jouer dans les processus de C2 et de renseignement et elles ont déjà reçu une grande attention pour les applications militaires. De nombreux projets courants du ministère de la Défense nationale (MDN) et aussi à R et D pour la défense Canada comportent une importante composante d'ASFI. Cependant, en dépit de l'importance donnée à l'ASFI dans plusieurs documents et projets stratégiques du MDN, les systèmes actuels et la technologie associée n'arrivent souvent pas à satisfaire les besoins exigeants des preneurs de décisions opérationnels; des percées majeures en science et technologie sont nécessaires pour vraiment atteindre le plein potentiel des technologies facilitantes associées et pour servir au mieux les communautés opérationnelles. L'effort rapporté ici est une étape en ce sens; il contribue à l'établissement d'une base solide sur laquelle un programme de R et D à long terme devrait être fondé.

Ce rapport ne donne qu'une vue d'ensemble initiale de la multitude d'aspects résultants de l'approche et du cadre holistiques; il s’avère nécessaire d'approfondir ces aspects pour embrasser vraiment cette approche et développer des systèmes de soutien appropriés et répondant aux besoins exigeants des communautés opérationnelles. Pour cette raison, des activités de R&D ont été et sont encore menées afin d’étudier plus à fond les concepts, paradigmes et techniques de représentation de la connaissance, et les processus, méthodes et systèmes de raisonnement pour leur utilisation dans des systèmes de soutien à l'ASFI basés sur la connaissance. Adopter une vue de l'ASFI centrée sur la connaissance ainsi que l'approche présentée dans ce rapport nécessite que la connaissance (c.-à-d., l'expertise) soit éventuellement acquise des experts du domaine (ED) des différents domaines d'application militaires et de la sécurité publique. À ce propos, les techniques d'ingénierie de la connaissance et ontologique ont été et sont encore étudiées en ce moment. Des sessions d'acquisition et de validation de connaissances avec des ED sont sur le point d'être effectuées.

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1. Introduction

Situation awareness (SAW) has emerged as an important concept supporting dynamic human decision-making in military and public security environments. Actually, SAW is a general concept that has been shown to be of interest in a very large number of settings. Given this wide interest for SAW, the author has previously proposed another concept, situation analysis (SA), defined as a process that provides and maintains a state of situation awareness for the decision maker(s) [Roy, 2001].

A key enabler to meeting the demanding requirements of situation analysis in future command and control (C2) and intelligence systems (i.e., in achieving high-quality situation awareness for optimal decision making) is data/information fusion. An initial lexicon defined data fusion as a process dealing with the association, correlation, and combination of data and information from single and multiple sources to achieve refined position and identity estimates, and complete and timely assessments of situations and threats as well as their significance [White, 1987]. This definition has evolved over the years, and multiple variants have been proposed. Recently, [Lambert, 2001] defined information fusion as the process of utilizing one or more information sources over time to assemble a representation of aspects of interest in an environment. Among the many reasons for interest in this technology, there is that data/information fusion:

- provides extended spatial and temporal coverage, increased confidence, reduced ambiguity, improved entity detection, etc.,
- allows for the management of large volumes of information and the correlation of seemingly unrelated, overlooked, or deceptive information to present a coherent representation of an evolving situation to a decision maker, and,
- enables the commander to cope with the complexity and tempo of operations in modern dynamic operational theatres.

Clearly, situation analysis and information fusion (SAIF) have a critical role to play, and have already received significant attention for military applications. Numerous ongoing projects of the Department of National Defence (DND) have an important SAIF component. Examples, just to name a few, are:

- Project No. 00000276: Land Force Intelligence, Surveillance, Target Acquisition and Reconnaissance (LF ISTAR)
- Project No. 00000806: Marine Security Operations Centres (MSOC)
- Project No. 00000624: Joint Information and Intelligence Fusion Capability (JIIFC)

However, despite the importance surrounding SAIF in many DND strategic documents and projects, the current supporting systems and the associated technology often fail to meet the demanding requirements of the operational decision makers, and major Science and Technology (S&T) advancements are required to really achieve the full potential of the related enabling technologies and to best serve the operational communities. In this line of thought, many R&D projects ongoing under the Technology Demonstration Program (TDP) at Defence R&D Canada (DRDC) have an important SAIF component as well:

- Joint Command Decision Support for the 21st Century (JCDS 21)
- Innovative Naval Combat Management Decision Support (INCOMMANDS)

SAIF is certainly expected to play a crucial role in the next generation of support systems for aiding decision makers in military and public security operations.

Taking into account the context described above, the author proposed in a previous report that developing and adopting a knowledge-centric view of situation analysis should provide a more holistic perspective of this process, leading to the development of better, more adequate SAIF support systems for the operational communities [Roy, 2007]. This was mostly based on the fact that *awareness* ultimately has to do with *having knowledge of something*. As discussed in [Roy, 2007], expert systems constitute a branch of AI that makes extensive use of specialized knowledge to solve problems at the level of a human expert. They are the paradigmatic application of artificial intelligence (AI) techniques to hard problems, and expert system technologies are expected to significantly contribute to the development of the future, state-of-the-art knowledge-based situation analysis support systems (SASSs).

Adopting the knowledge-centric view of situation analysis, a corresponding well-structured development process needs to be defined and followed to build appropriate knowledge-based SASSs. Combining elements of information fusion and knowledge-based systems, this report presents a holistic approach and framework, including some recommended high-level steps discussed in the report, for the overall development and evaluation of any knowledge-based SASS. Emphasis is given to the knowledge-centric aspects of the approach.

The report doesn't present “solutions”, or findings and results of completed activities. The intent is more to provide a fair description of a suitable development approach, in order to contribute to the set up of a foundational R&D framework for two DRDC projects that are just starting under the Applied Research Program (ARP):

- SATAC (Situation Analysis for the Tactical Army Commander), and,
- CKE-4-MDA (Collaborative Knowledge Exploitation for Maritime Domain Awareness), formerly known as AKAMIA (Advanced Knowledge Acquisition for Maritime Information Awareness).

The report is organized as follows. Section 2 first provides an overview of the holistic approach and framework proposed by the author. Then the description of this framework begins in Section 3 with a discussion on organizing the knowledge in the target application domain. This is a fundamental step of the approach, as the application domain characteristics will define the fundamental skeleton of the SASS. The notion of *expert* is presented, as the development of a SASS necessarily includes the participation of Subject Matter Experts (SMEs) from the application domain. This is followed with a discussion on documented knowledge.

From a SASS design perspective, the identification of the critical information required for situation analysis and decision-making can be done through the application of cognitive theories and cognitive system engineering (CSE) techniques; this is the topic of subsection 3.3. In particular, a pragmatic CSE approach, known as the Applied Cognitive Work Analysis (ACWA), is briefly described. Software engineering is then discussed, as developing a computer-based SASS ultimately has to do with developing software. An approach is finally proposed to develop highly effective SASSs, based on "combining" cognitive and software engineering methodologies into an integrated approach. Annex A of this report actually provides an example of a statement of work (SOW) that could be used for a contract to capture and document the requirements for a SASS in a specific domain.

Section 4 discusses the second of the four main components of the holistic framework, i.e., developing situation analysis support system capabilities. On one hand, the process of building a knowledge base is called knowledge engineering. It deals with knowledge acquisition, representation and validation, and also with inference, explanation and justification, and maintenance. On the other hand, ontological engineering refers to the set of activities that concern the ontology development process and life cycle, the methods and methodologies for building ontologies, and the tool suites and languages that support them. Knowledge and ontological engineering are both discussed in Section 4, which also presents the concept of a "processing node" for data and information fusion and for situation analysis.

A very important step in the development of any SAIF system is the establishment of the knowledge/information/data (KID) processing tree; this is the topic of subsection 4.4. Then, following a brief discussion on adaptive fusion, the concept of a knowledge management and exploitation server is introduced from the perspective of the a priori KID that is required to support the SAIF processes.

Subsection 4.8 is about architectural issues, an important facet of any serious SASS development project. Aspects of an adequate processing architecture for SAIF, of a system-of-systems integration architecture, and of data models and structures are presented. A discussion of human-computer interaction ends Section 4.

From a research and development perspective, SASS system developers need capabilities that allow them to assess if a proposed SASS is working properly, as expected. A set of tools is thus required to support the designer/developer/user/operator in quantitatively assessing the performance of the SASS algorithms and techniques. In this regard, Section 5 describes the third main component of the holistic framework, i.e., the evaluation in laboratory testbeds using modeling and simulation. Situation awareness measurement and quality assessment, stimulation capabilities for the SASS applications and performance evaluation capabilities are briefly discussed in this section.

The fourth and last of the main components of the holistic framework, i.e., field demonstrations and experiments, is the topic of Section 6. The discussion in this section is mostly based on the view of the U.S. Department of Defense (DoD) Command and Control Research Program (CCRP), as presented in [Alberts et al, 2002].

As previously mentioned, the expert system technologies look very promising for the implementation of knowledge-based SASSs. Hence, many aspects associated with the development of expert systems are discussed in Section 7. Expert system development life cycle and team participants, stages in participatory design, development tools/shells and typical development difficulties are topics addressed in this section.

Finally, concluding remarks are provided in Section 8.

2. Overview of the Holistic Approach and Framework

To build an appropriate knowledge-based situation analysis support system (SASS), a well-structured development process needs to be adopted and followed. Figure 1 illustrates elements of such a development process.

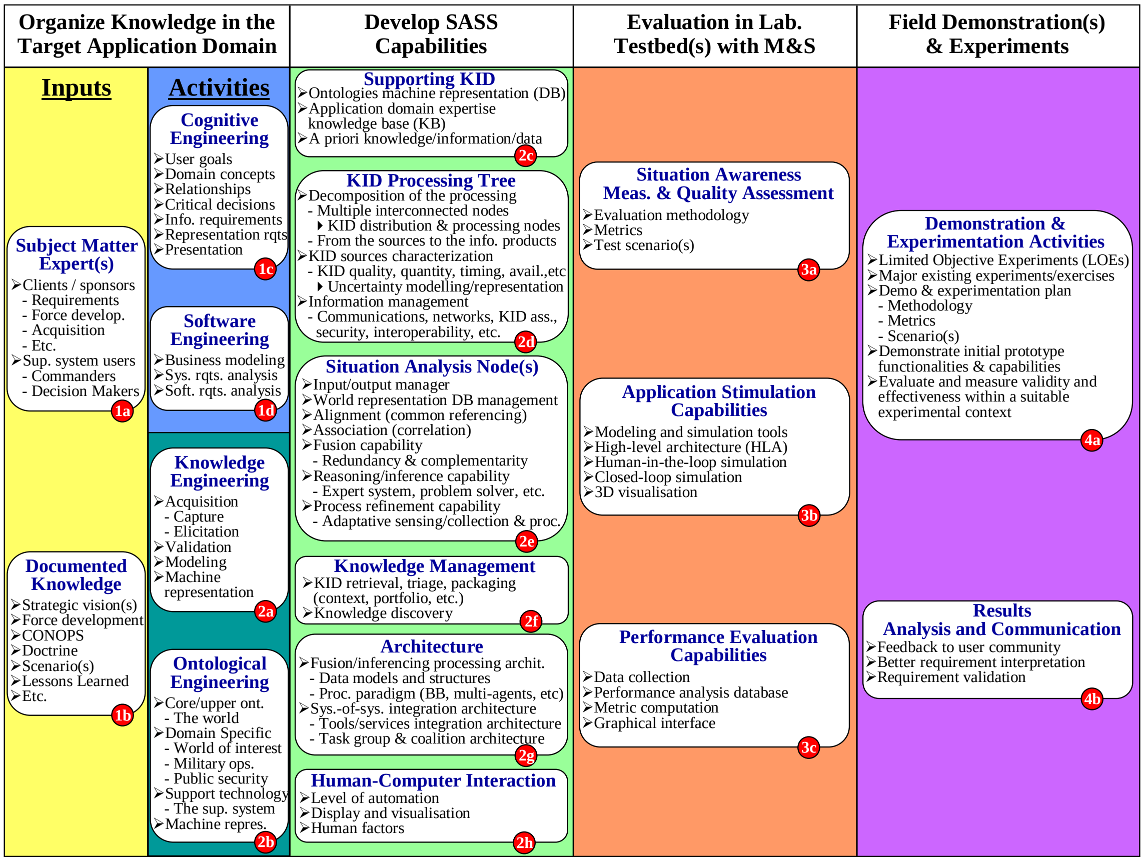

Figure 1: Holistic approach and framework for the building of knowledge-based SASSs

Combining elements of information fusion and knowledge-based systems, Figure 1 presents a holistic approach and framework, including some recommended high-level steps discussed in this report, for the overall development and evaluation of any knowledge-based SASS. Those interested in a complete program for the development of an entire system may use the holistic approach of Figure 1 as a checklist; so that one can ensure that all important and necessary aspects are taken into account. The framework also provides some guidelines regarding an appropriate sequence for the various tasks that must be performed. Those working on very specific aspects of the situation analysis and information fusion domains can use the holistic framework to better appreciate how and where their work fits into the big picture.

In line with the engineering guidelines provided in [Steinberg, Bowman, White, 1998], the design and development initially flow from overall system requirements and constraints to a specification of the support capability's role. Some further partitioning results in the development and specification of a knowledge/information/data (KID) processing tree structure and of the corresponding situation analysis processing nodes. Pattern analysis of the requirements for each node allows for the selection of appropriate processing techniques, based on analysis and experience of applicability in the specified conditions. In each phase, the analysis of requirements leads to a further functional partitioning. Performance analysis of the resulting point design can lead to further analysis, repartitioning and redesign, or to the initiation of the next design phase. Thus, this process is amenable to implementation via waterfall, spiral or other development methods.

Many aspects of the development process showed in Figure 1 are discussed in [Breton, Paradis, Roy, 2002]. An important challenge is to develop a SASS that, on one hand, takes advantage of all the technological opportunities but, on the other hand, is totally compatible with the way the human executes the tasks to be supported. The development of SASSs thus includes the participation of experts from the application domain, i.e., the Subject Matter Experts (SMEs) in Figure 1, as well as system designers and human factor specialists, in order to ensure a cognitive fit between the SASS and the decision-makers, so as to maximize decision-making effectiveness.

Figure 2 shows a different perspective of the SASS development process, including some information on the typical progression of the process, with feedback paths.

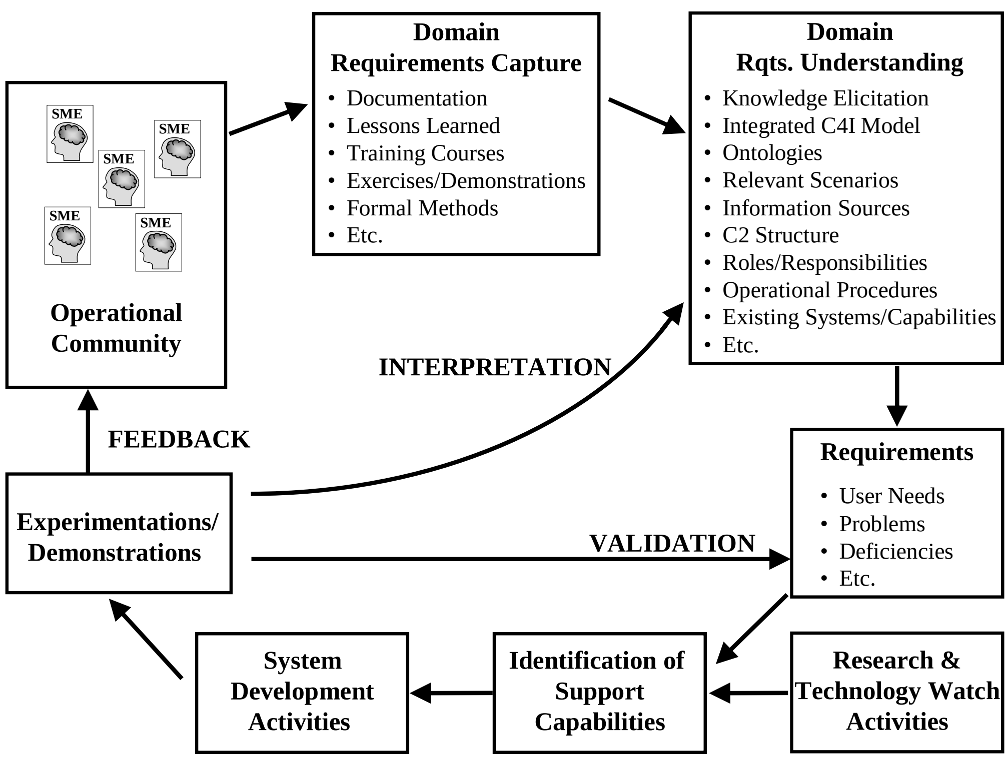

Figure 2: SASS development process

The process begins with the identification of SMEs (mostly decision-makers) from the operational community. It then proceeds with the capture and understanding of the requirements of the particular application's domain of interest. This is a fundamental step, as the application's domain characteristics will define the fundamental skeleton of the SASS and ultimately, the form of the SASS knowledge model communicated to the human practitioner controlling the domain. This step can be initiated through reading appropriate documentation of the domain, through an analysis of documented lessons learned, and through an active participation in training courses and/or exercises/demonstrations with end users. However, a serious SASS development process must include formal interviews with SMEs, following cognitive engineering methods. This step includes the use of current cognitive theories and models to interpret and understand the impact of the results and findings from a human factor perspective.

The analyses above lead to the identification of user needs, problems and deficiencies in the form of explicit system/software requirements. Then, technological solutions are identified to address the requirements, taking into account the findings of research and technology watch activities, leading to system development activities. A serious system development process, if the project's timeframe and appropriate resources permit, should follow formal software engineering methodologies.

Testing procedures and demonstrations/experimentations are required to validate the technological solutions from the human performance and operational perspectives. Transparency must be one characteristic of the development process. With testing/demonstration/ experimentation results presented as a feedback, the SMEs can understand the link between their requirements and the solutions provided at the end of the development process to answer these requirements. Moreover, discussions around these results may lead to the identification of other problems experienced by the SMEs, or potential problems created by the new SASS. On one hand, being more involved into the development process through the feedback process allows the SMEs to develop a better understanding about the way the SASS is built, which can result in a better acceptation and a higher level of confidence about the SASS. On the other hand, having more contacts with the SMEs helps the team members be more aware of the SME reality, which can lead to the development of a more appropriate SASS.

The remainder of this document further discusses the components of the holistic approach and framework showed in Figure 1 for the building of knowledge-based SASSs. Emphasis is given to the knowledge-centric aspects of the approach.

3. Organizing the Knowledge in the Target Application Domain

The SASS development process of Figure 1 begins with organizing the knowledge in the target application domain. This is a fundamental step, as the application domain characteristics will define the fundamental skeleton of the SASS.

3.1 Subject Matter Experts

As previously mentioned, the development of situation analysis support systems necessarily includes the participation of experts from the application domain, i.e., the Subject Matter Experts (SMEs) in Figure 1. Actually, the process begins with the identification of SMEs (mostly decision-makers) from the operational community.

An expert is a person who has expertise in a certain area [Giarratano, Riley, 1998]. This being said, it is sometime difficult to define what an expert is because one actually talks about degrees or levels of expertise [Turban, Aronson, 1998]. The real question then becomes: how much expertise should a person possess before qualifying as an expert? In general, the term *expert* connotes both specialization in narrow problem-solving areas or tasks and substantial competence [Stefik, 1995] [Turban, Aronson, 1998]. Experts are people having substantial training and exceptional skill. They have knowledge or special skills that are not known or available to most people [Giarratano, Riley, 1998]. They have judgement, experience, and methods along with the ability to apply these talents to give advice and solve problems [Turban, Aronson, 1998]. An expert can solve problems that most people cannot solve or can solve them more efficiently (but not as cheaply) [Giarratano, Riley, 1998]. Experts can take a problem stated somewhat arbitrarily and convert it to a form that lends itself to a rapid and effective solution. Such problem-solving ability is necessary to qualify as an expert, but not sufficient. Typically, human experts possess the following characteristics [Turban, Aronson, 1998], i.e., they:

- recognize and formulate the problem,
- know which facts are important and understands the meaning of the relationships among facts,
- can call up patterns from their experience (excellent recall),
- solve problems quickly and fairly accurately,
- explain the solution and the results, i.e., explain what they do (and sometimes how they do),
- know the extent of their knowledge,
- determine if their expertise is relevant,
- judge the reliability of their own conclusions,
- qualify their advice as the problem reaches the limits of their knowledge,
- know when they are stumped,

- degrade gracefully (awareness of limitation),
- communicate with other experts,
- change their points of view to suit a problem,
- restructure knowledge whenever needed,
- break rules whenever necessary (i.e., know the exceptions to the rules),
- learn new things about the domain from experience,
- learn from past successes and mistakes,
- transfer knowledge from one domain to another, and,
- use tools, such as rules of thumb, mathematical models, and detailed simulations to support their decisions.

Expert activities must be done efficiently (quickly and at low cost) and effectively (with high-quality results) [Turban, Aronson, 1998]. Experts "degrade gracefully", meaning that as they approach the boundaries of their knowledge, they gradually become less proficient at solving problems, but can still develop reasonable solutions. An expert generally can give a measure of how confident he/she is in its solutions when reaching his/her boundaries of knowledge. It takes a long time (usually several years) to become an expert, and novices become experts only incrementally.

3.2 Documented Knowledge

Knowledge engineering practice, like other scientific or engineering enterprise, begins by trying to ascertain what is already known [Stefik, 1995]. In line with this idea, the capture and understanding of the requirements of the particular application domain of interest can be initiated through reading appropriate documentation of the domain. For a number of reasons, this is an important aspect:

- The subject matter experts are, in general, very busy people. It may be difficult to obtain from the experts some sufficient spare time to participate in the domain knowledge acquisition sessions required for SASS development.
- Many documents already contain domain expert knowledge that is readily available. Actually, a lot of the most relevant documents are indeed written by the domain experts themselves.
- As the time of the experts is precious, it is of the utmost importance for the SASS developers to arrive well prepared for the domain knowledge acquisition sessions. Reading and understanding the available documentation of the domain is the best way to prepare for such sessions.

Examples of typical relevant documents are:

- strategic vision documents,
- force development documents,

- CONOPS,
- doctrine,
- scenarios, and,
- lessons learned.

Scenarios are of particular importance for the acquisition of domain knowledge. According to [Merriam-Webster, 2003], a scenario is:

- an outline or synopsis of a play,
- a sequence of events,
- an account or synopsis of a possible course of action or events.

A vignette is a short descriptive literary sketch, a brief incident or scene. The spectrum of vignettes and scenarios ranges from single attack involving a small number of interacting platforms to complex situations with several events involving various threats over a longer period of time. The quantity and the type of documentation vary from one scenario to another. It goes from a limited description on a single page of the involved platforms and their trajectories, to lengthy historical, cultural and geopolitical contexts, armed forces structures, geographical data, etc., over hundreds of pages.

As mentioned above, documented scenarios are of particular importance:

- The scenarios contain expertise from the domain experts.
- One can learn about the application domain by reading scenarios.
- The scenarios are constructed with (and thus explicitly express) many domain concepts that could be captured during a conceptualization effort, eventually leading to the development of an ontology of the domain.
- Appropriate data models (e.g., an information exchange data model) can be built by reviewing the scenario elements.
- The scenarios provide a lot of a priori knowledge that must be captured in various databases or knowledge bases, and that will be used to support the fusion and reasoning processes within the SASS.
- The scenarios provide the required material for their implementation and execution in simulators / stimulators for SASS testing and performance evaluation:
    - Actors
    - Platforms
    - Sensors / Weapons
    - Kinematics / Trajectories
    - Terrain, Weather
    - Etc.

3.3 Cognitive Engineering

To efficiently support humans in their situation analysis and decision-making processes, the technology has to be designed to provide only (and all) the critical information required for these processes, i.e., the data and information that enhance the decision maker's situation awareness (SAW), which in turn increases the probability of an efficient decision-making process [Roy, Breton, Paradis, 2001]. From a SASS design perspective, the identification of the critical information can be done through the application of cognitive theories and cognitive system engineering (CSE) techniques.

Imagine being given the task of designing a decision support system to aid military commanders in planning troop movements. How would you determine the information to display? How would you determine the format in which to display the information in order to facilitate effective decision making? How would you effectively distribute tasks across team members (and across automated systems)? How would you know when you had developed a usable and effective system that leads to increased performance?

These are the types of design questions that can be addressed by the methods of cognitive engineering [Bonaceto, Burns, 2004]. Cognitive engineering is an interdisciplinary approach to designing computerized systems intended to support human performance [Roth, Patterson, Mumaw, 2001]. It encompasses the fields of human factors, human-computer interaction, cognitive psychology, computer science, artificial intelligence and other related fields. The methods of cognitive engineering consider workers and the tasks they perform as the central drivers for system design.

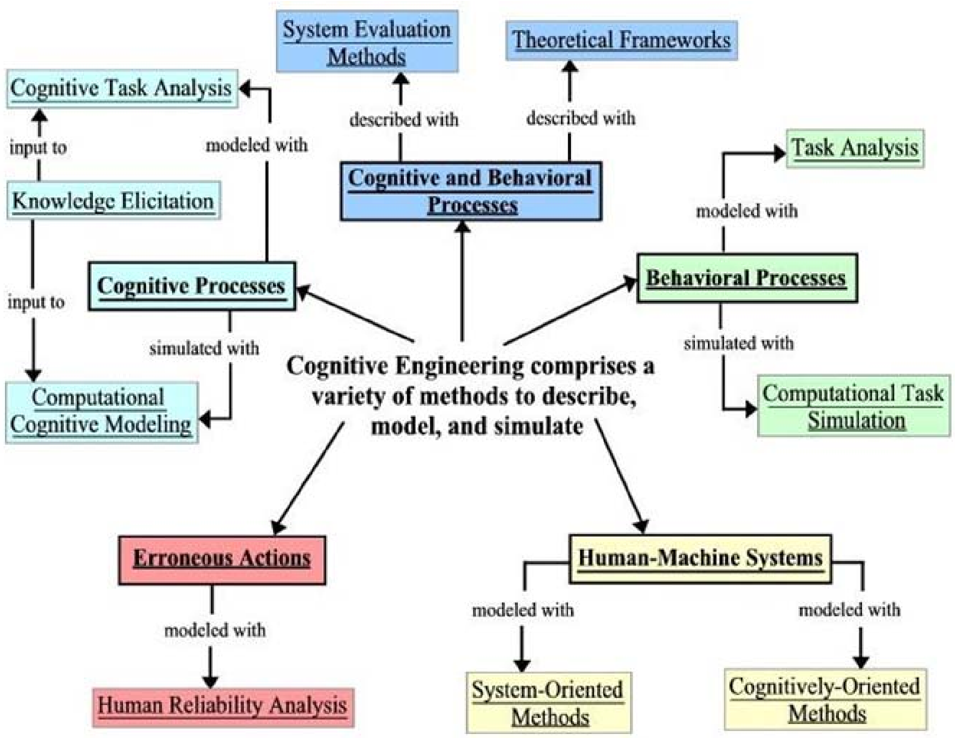

Figure 3: The methods of cognitive engineering [Bonaceto, Burns, 2004]

As Figure 3 shows, the methods of cognitive engineering are quite diverse [Bonaceto, Burns, 2004]. Certain methods aim to get an understanding of users and tasks by constructing quantitative models of expert reasoning. Other methods focus on documenting the key decisions made in the domain and the information required to make those decisions. The aim is to develop systems that support cognitive functions such as problem solving, planning, decision making, perception, memory, situation assessment, monitoring, and prioritizing.

Questions that drive design and are addressed by methods of cognitive engineering include [Bonaceto, Burns, 2004]:

- What are the goals and constraints of the application domain?
- What range of tasks do domain practitioners perform?
- What strategies do they use to perform these tasks today?
- What factors contribute to task complexity?
- What tools can be provided to facilitate the work of domain practitioners and achieve their goals more effectively?

The methods of cognitive engineering have tremendous potential to impact some of the most difficult aspects of system engineering, especially in the command and control domain [Bonaceto, Burns, 2004]. In fact, it has been opined that the only way to deal with the increased complexities in future command and control, including the vast amounts of available data, the pressure to make timely decisions utilizing the totality of that data, and the reduced manpower and cost goals, is to follow a human-centered approach to system engineering [Perry et. al., 1999]. Below are three key challenges that command and control system engineers must address [Bonaceto, Burns, 2004]:

- <u>Smaller</u>: Reducing the footprint.
- <u>Better</u>: Improving coordination between people and automation.
- <u>Faster</u>: Reducing the timeline.

Cognitive engineering methods can effectively address these challenges.

Cutbacks in defence spending have forced military organizations to do more with less. In this regard, a key design challenge is to design new systems and re-engineer existing systems in order to maintain optimal performance with fewer people. [Militello, Klein, Crandall, and Knight, 1998] provide key findings of an extensive analysis of successful manpower reduction efforts in the corporate and military sectors. Along with each finding, [Bonaceto, Burns, 2004] provide a discussion as to how it can be addressed with cognitive engineering methods.

Advances in technology have made possible new levels of automation that have had many effects on operational settings. In settings such as airplane cockpits and power plants, automation has changed the role of the operator from one of manual control to one of supervisory control. In the command and control domain, systems have been developed to automate certain lower level decision making tasks, such as pairing weapons with targets. A variety of unforeseen issues and setbacks have arisen, including:

- Systems often don't provide operators with justifications for their actions or conclusions, leading operators to ask of the automated system what is it doing? why is it doing that? what is it going to do next?
- People aren't aware of the uncertainty and unreliability of information propagated by the automated system, leading to issues such as overtrust or undertrust in automation.
- People may lose situation awareness and have difficulty taking control when an automated system fails.

In this regard, a key design challenge is to build automated systems that amplify and augment human cognition. Traditionally, the human factors community has regarded automation as a problem of function allocation. That is, the problem is fundamentally a matter of deciding which system functions should be performed by machines and which by people. With this approach, either the human does all the work or the machine does all the work. The current approach advocated by the cognitive engineering community is one that views the humans and machines as forming a joint cognitive system where people and intelligent agents work together to perform the work of the system. So the goal is to join people and automation together into a successful collaborative team. People need to be able to coordinate, trust, supervise, and cooperate with automated systems.

In some situations, minutes or even seconds can make the difference between success and failure. For example, this situation occurs in the prosecution of Time Critical Targets (TCTs). TCTs are those for which there is a limited amount of time available to work through the kill chain cycle (i.e. find, fix, track, target, engage, and assess). In this regard, a key design challenge is to design new systems and re-engineer existing systems that allow optimal decisions to be made in less time. Many of the cognitive engineering applications addressing reducing manpower and improving coordination between people and automation equally apply to reducing the timeline, since automation will most likely play a large role in any timeline reduction effort. Human-human collaboration also plays a critical role in the successful prosecution of time critical targets. Thus, optimization of both human-machine and human-human collaboration will most likely be the driving factors behind a timeline reduction effort.

Cognitive engineering methods have been organized into one of five primary categories [Bonaceto, Burns, 2004]:

- modeling cognitive processes,
- modeling behavioural processes,
- describing cognitive and behavioural activities,
- modeling erroneous actions, and,
- modeling human-machine systems.

While some methods overlap multiple categories, each method is assigned to a "primary" category. [Bonaceto, Burns, 2004] further discuss these methods.

3.3.1 Applied Cognitive Work Analysis (ACWA)

Cognitive Task Analysis (CTA) and Cognitive Work Analysis (CWA) are both often put forward as techniques that can provide, via interviews with SMEs, the set of critical information that must be made available to reach optimal decisions. Unfortunately, these approaches are well suited to deal with decision support issues but are in practice very expensive to conduct, time consuming and more importantly, generally inefficient from a design process perspective. With the latter limitations in mind, a pragmatic CSE approach, known as the Applied Cognitive Work Analysis (ACWA), has been developed to bridge, in a structured, efficient and converging way, the gap between cognitive analysis and design [Paradis, Breton, Bossé, Elm, Potter, 2002]. This ACWA modeling method is a pragmatic adaptation of the CWA method in order to cope with the limitations related to applying CWA. As a result, the cost to conduct CSE analyses using the ACWA approach is reduced and the analysis-design efficiency is significantly improved, thereby facilitating the identification of decision-aiding concepts suited to provide effective decision support. Figure 4 provides a visual depiction of the sequence of methodological steps and their associated output artefacts, as well as an indication that the process is typically repeated in several expanding spirals, each resulting in an improved support system. [Elm, Potter, Gualtieri, Roth, Easter, 2002] describes each step of this approach in detail.

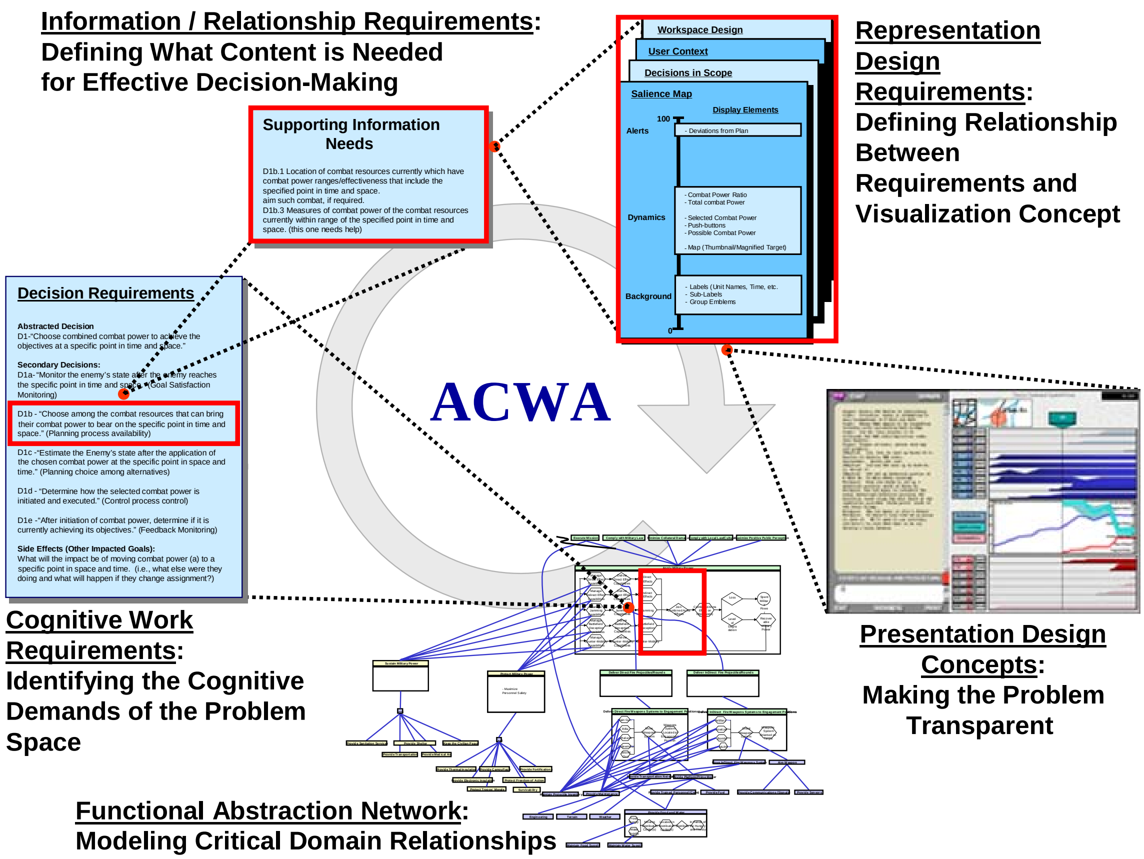

Figure 4: Applied Cognitive Work Analysis (ACWA) [Elm, Potter, Gualtieri, Roth, Easter, 2002]

3.4 Software Engineering

Developing a computer-based situation analysis support system ultimately has to do with developing software. Hence, as for any large-scale software system, the development of a large-scale SASS should follow an appropriate software development methodology for the creation and management of the required software. The term software engineering refers to engineering practices for developing software [Stefik, 1995]. Software engineering arose as a subject as it was deemed desirable to control the development of software and as it became apparent that the methods and techniques that had been used in developing hardware were not appropriate for software. The accommodation of frequent changes is one of the central issues that any successful approach to software engineering must take into account.

This sub-section briefly discusses two software development frameworks often put forward by the software development communities. The business modeling and system/software requirements analysis aspects of software engineering are of particular relevance to documenting the target application domain.

3.4.1 ISO/IEC 12207 International Standard

As discussed in [IEEE, 1998-A], software is an integral part of information technology and conventional systems, such as transportation, military, medical care, and finance. Over many years, there has been a proliferation of standards, procedures, methods, tools, and environments for developing and managing software. This proliferation has created difficulties in software management and engineering, especially in integrating products and services. The software discipline needed to migrate from this proliferation to a common framework that could be used by software practitioners to “speak the same language” to create and manage software. The ISO/IEC 12207 international standard, published by the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC), provides such a common framework for software life cycle processes, with well-defined terminology and that can be referenced by the software industry.

The processes in ISO/IEC 12207 form a comprehensive set. An organization, depending on its purpose, can select an appropriate subset to fulfill that purpose. The standard is, therefore, designed to be tailored for an individual organization, project, or application. The tailoring process has to do with the deletion of non-applicable processes, activities, and tasks. The standard is also designed to be used when software is a stand-alone entity, or an embedded or integral part of the total system.

3.4.2 Rational Unified Process (RUP)

The Rational Unified Process (RUP) is a software engineering process [Rational, 1998]. It provides a disciplined approach to assigning tasks and responsibilities within a development organization. Its goal is to ensure the production of high-quality software that meets the needs of its end-users, within a predictable schedule and budget. It captures many of the best practices in modern software development in a form that is suitable for a wide range of projects and organizations.

The RUP activities create and maintain models. Rather than focusing on the production of large amount of paper documents, the unified process emphasizes the development and maintenance of models—semantically rich representations of the software system under development. RUP is supported by tools, which automate large parts of the process. These tools are used to create and maintain the various artefacts—models in particular—of the software engineering process: visual modeling, programming, testing, etc. The unified process is a configurable process that fits small development teams as well as large development organizations, and is founded on a simple and clear process architecture that provides commonality across a family of processes. Yet, it can be varied to accommodate different situations. Details of the Rational Unified Process can be found in [Rational, 1998] or in [Kruchten, 2000].

3.5 Combining Cognitive and Software Engineering Methodologies

Figure 5 illustrates a proposed approach to develop highly effective situation analysis support systems, based on combining cognitive and software engineering methodologies into an integrated approach.

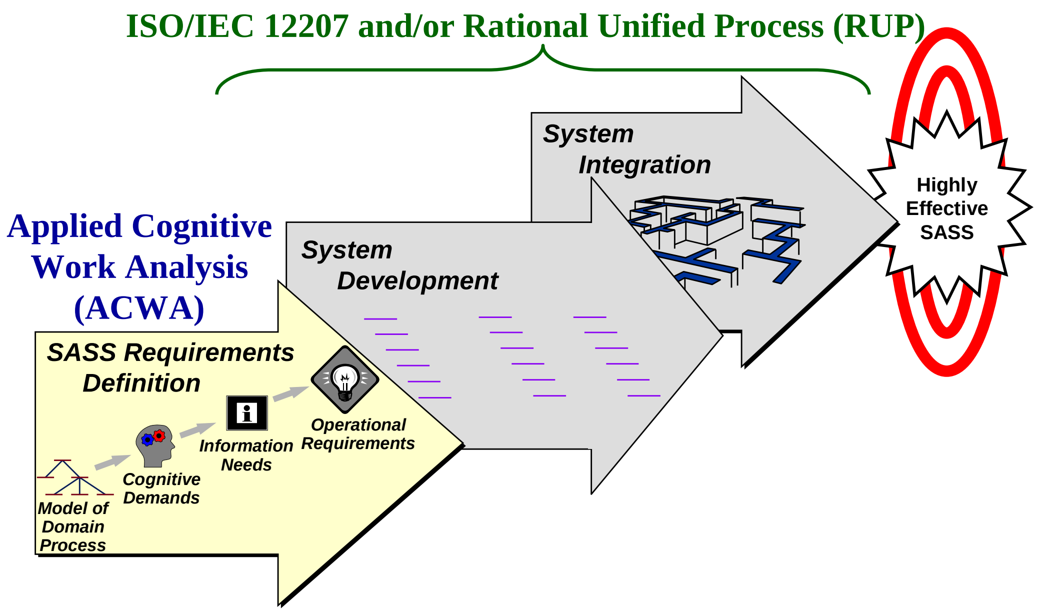

Figure 5: SASS development methodology example, here based on ACWA [Paradis, Breton, Bossé, Elm, Potter, 2002] and well-known software engineering methods

As previously mentioned, the development of a large-scale SASS should follow an appropriate software engineering methodology for the creation and management of the required software. It is proposed to use an appropriate mix of two methodologies often put forward by important software development teams, i.e., ISO/IEC 12207 and the Rational Unified Process. These methodologies would be adapted and tailored to create a hybrid approach that would meet the needs and scope of the SASS development process. Clearly, using ISO/IEC 12207, RUP, or a clever combination of both methodologies would provide good results for most software development projects. However, this is not sufficient for the development of an effective decision support system. Hence, it is proposed to combine the software engineering methodology with a cognitive engineering methodology. In this regard, Applied Cognitive Work Analysis seems to be an appropriate candidate. Figure 6 shows the relationships between the various development activities put forward by these three methodologies.

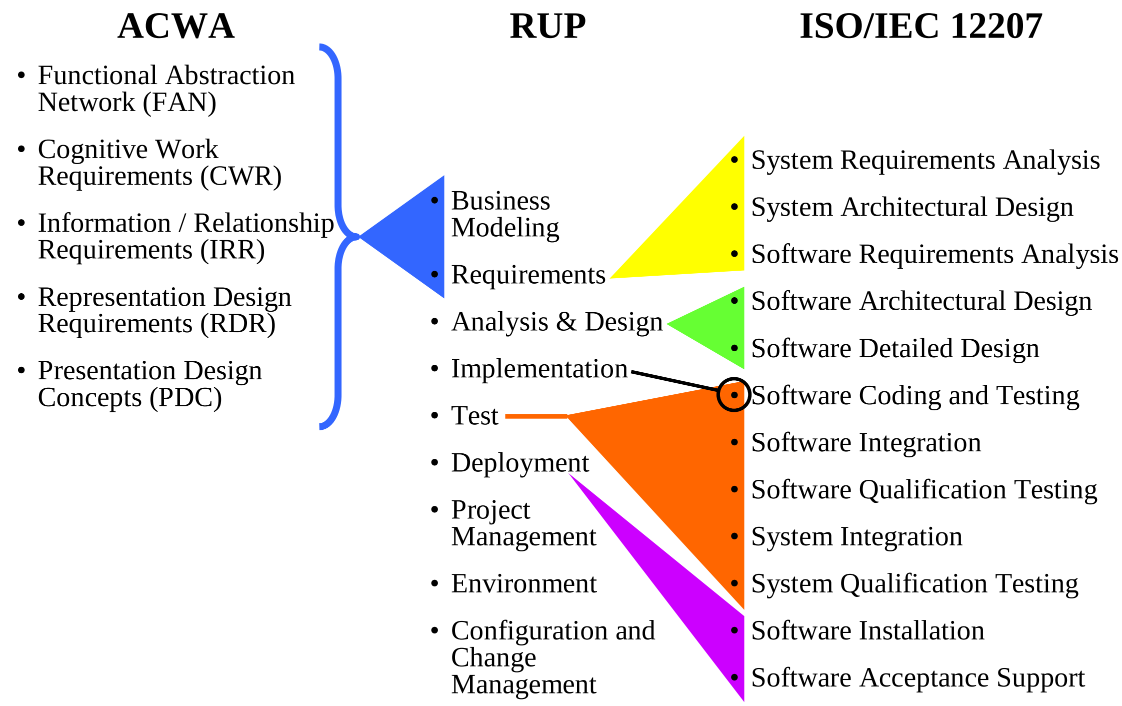

Figure 6: SASS development activities

3.6 Capturing and Documenting the SASS Requirements

Figure7 shows how the three methodologies would be combined and used to derive the requirements for a given SASS development project.

The proposed approach for the identification of the SASS requirements includes the modeling of the application domain from a cognitive, decision-making perspective (i.e., the capture, grasp and documentation of the goals, analysis processes, critical decisions and corresponding information requirements). Combined with formal business modeling activities, this approach will examine and help sort out the decision-support challenges, leading to the identification and definition of proper situation analysis support capabilities, and their documentation expressed as system and software requirements.

Based on the results of the ACWA and business modeling activities, and working with the SMEs from the operational community, a Concept of Operations (CONOPS) will be developed to describe, in users' terminology, how the system should operate to meet the users' needs for the system. The concept of operations description should include elements such as a description of the current situation or system, a justification for and the nature of changes, concepts for the proposed system, operational scenarios, summary of impacts, etc. [IEEE, 1998-B]. Building on the artefacts of the ACWA, the business model and the CONOPS, the requirement analysis activity will identify and document the system and software requirements for the SASS (system requirements specification, software requirements description, etc.) following guidelines provided by the ISO/IEC 12207 and the RUP.

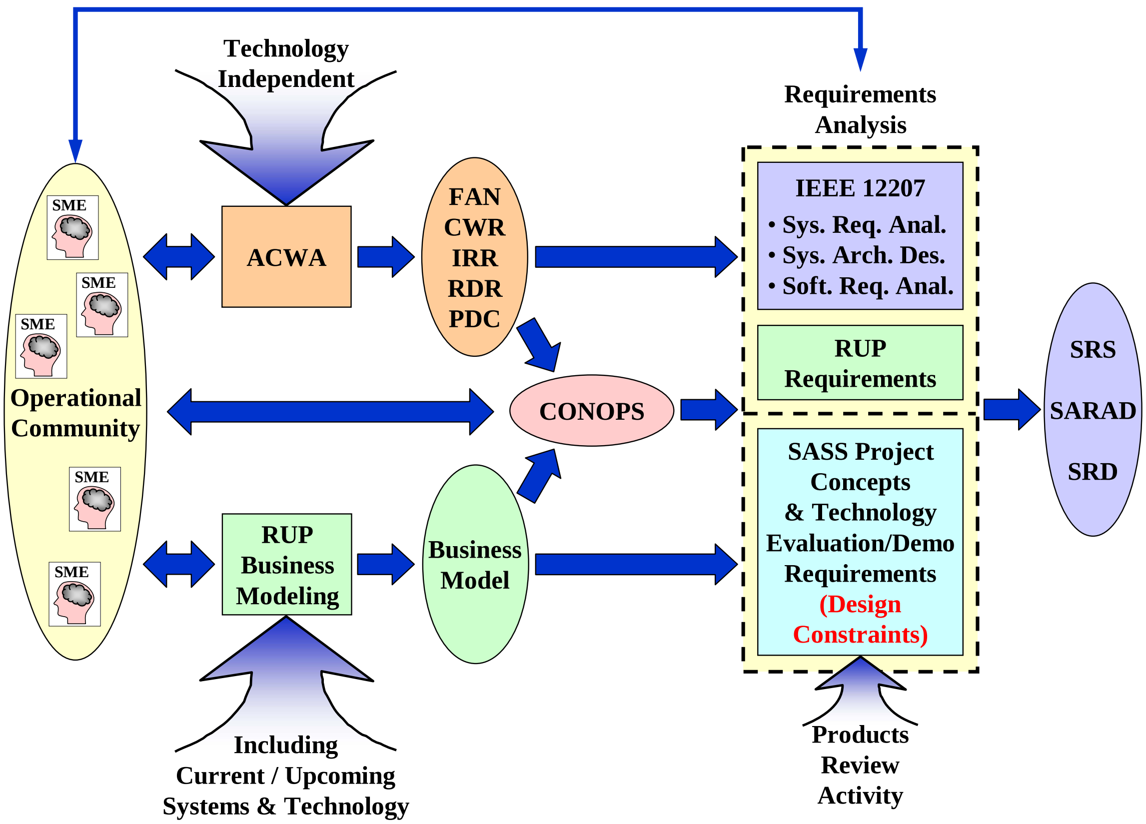

Figure 7: SASS requirements identification

Annex A provides an example of a statement of work (SOW) that could be used for a contract to capture and document the requirements for a SASS in a specific domain.

4. Developing Situation Analysis Support System Capabilities

The cognitive and software engineering analyses discussed in the previous sub-sections eventually lead to the identification of user needs, problems and deficiencies in the form of explicit system/software requirements. Then, technological solutions are identified to address these requirements, taking into account the findings of research and technology watch activities leading to system development and integration activities.

Note in Figure 1 that knowledge and ontological engineering fall on both organizing the knowledge in the target application domain and developing the situation analysis support system capabilities. These two topics are briefly discussed next. A more complete discussion of these fields can be found in [Roy, Auger, 2007-A].

4.1 Knowledge Engineering

The process of building a knowledge base is called knowledge engineering [Russell, Norvig, 1995]. It deals with knowledge acquisition, knowledge representation, knowledge validation, inference, explanation and justification, and maintenance. A knowledge engineer is someone who investigates a particular domain, determines what concepts are important in that domain, and creates a formal representation of the objects and relations in the domain. Often, however, the knowledge engineer is trained in representation, but he/she is not an expert in the domain at hand. The basic model of knowledge engineering thus portrays teamwork in which a knowledge engineer interacts with one or more human experts in building the knowledge base [Turban, Aronson, 1998]. It is the expert's job to provide knowledge about how he/she performs the task that the knowledge-based system will support or perform.

4.1.1 Knowledge Acquisition

Knowledge acquisition is the process of collecting, extracting, transferring, accumulating, structuring, transforming and organizing knowledge (e.g., problem-solving expertise) from one or more knowledge sources (human experts, books, documents, sensors, or computer files) for constructing or expanding a knowledge base [Turban, Aronson, 1998].

A commonly used form of knowledge acquisition is face-to-face interview analysis. It is an explicit technique and it appears in several variations. It involves a direct dialog between the expert and the knowledge engineer. Information is collected with the aid of conventional instruments (such as tape recorders or questionnaires), and it is subsequently transcribed, analysed, and coded. In the interview, the expert is presented with a simulated case or, if possible, with an actual problem of the sort that the expert system will be expected to solve. The expert is asked to “talk” the knowledge engineer through the solution.

Unfortunately, acquiring knowledge from experts is a complex task. This process has been identified by many researchers and practitioners as a (or even as *the*) bottleneck that currently constrains the development and construction of expert systems and other artificial intelligence

(AI) systems. The multiplicity of sources and types of knowledge contribute to the complexity of knowledge acquisition. Note that there are programs that learn by themselves to emulate the expert; these are programs based on induction and artificial neural systems. Some rule-based expert systems allow the system to learn the rules by example, through rule induction, in which the system creates rules from tables of data.

4.1.2 Knowledge Representation Methodology

Knowledge representation is an important issue [Roy, Auger, 2007-B]. The process of representing knowledge of a domain goes through several stages. The following five-step methodology can be used [Russell, Norvig, 1995]:

- Decide what to talk about.
- Decide on a vocabulary of predicates, functions, and constants.
- Encode general knowledge about the domain.
- Encode a description of the specific problem instance.
- Pose queries to the inference procedure and obtain answers.

One should note that the bulk of work in knowledge engineering involves not the selection of a suitable knowledge representation language, but deciding what to say in that language [Ginsberg, 1993].

4.1.3 Knowledge Validation and Verification

There may be inconsistencies, ambiguities, duplications, or other problems with the expert's knowledge that are not apparent until attempts are made to formally represent the knowledge in a knowledge-based system [Giarratano, Riley, 1998]. The process of developing such a system thus has an indirect benefit since the knowledge of human experts must be put into an explicit form for computer processing. Because the knowledge is then explicitly known instead of being implicit in the expert's mind, it can be examined for correctness, consistency, and completeness. The knowledge must be validated and verified (for example, by using test cases) until its quality is acceptable [Turban, Aronson, 1998]. Test case results are usually shown to the expert to verify the accuracy of an expert system. The knowledge may then have to be adjusted or re-examined, which improves the quality of the knowledge [Giarratano, Riley, 1998].

4.2 Ontological Engineering

As discussed in [Roy, Auger, 2007-B], a definition of the term *ontology* that is appropriate for the development of knowledge-based SASSs is *a formal, explicit specification of a shared conceptualization* [Struder et al, 1998]. Ontological engineering refers to the set of activities that concern the ontology development process, the ontology life cycle, the methods and methodologies for building ontologies, and the tool suites and languages that support them [Roy, Auger, 2007-A]. The ontology development process refers to which activities are performed when building ontologies. [Gómez-Pérez et al, 2004] presents the main methodologies and methods used to build ontologies from scratch, by reusing and re-engineering other ontologies, by a process of merging, or, by using an ontology learning approach.

Development-oriented activities for an ontology are grouped into pre-development, development and post development activities [Gómez-Pérez et al, 2004]. During the pre-development, an environment study is carried out to know the computer systems where the ontology will be used, the applications where the ontology will be integrated, etc. Also during the pre-development, the feasibility study answers questions like: is it possible to build the ontology? Is it suitable to build the ontology?, etc. Once in the development phase, the specification activity states why the ontology is being built, what its intended uses are, and who the end-users are (note that some consider specification as a pre-development activity). The result of this activity is an ontology description (usually in natural language) that will be transformed into a conceptual model by the conceptualization activity, which structures the domain knowledge into meaningful models at the knowledge level. The formalization activity transforms the conceptual model into a formal or semi-computable model. The implementation activity builds computable models in an ontology language. During the post-development, the maintenance activity updates and corrects the ontology if needed. Also during the post-development, the ontology is (re)used by other ontologies or applications.

Ontology support activities include a series of activities performed at the same time as the development-oriented activities, without which the ontology could not be built [Gómez-Pérez et al, 2004]. They include knowledge acquisition, evaluation, integration, merging, alignment, documentation and configuration management.

4.3 Situation Analysis Processing Nodes (Fusion/Inference)

The concept of a processing node for data and information fusion, as shown in Figure 8, has been introduced in the framework of the fusion model proposed by the Joint Directors of Laboratories' Data and Information Fusion Group (JDL DIFG) [Steinberg, Bowman, White, 1998]. According to this fusion node paradigm, the node processes the data/information provided by the sources (or other, prior fusion nodes) at the input, to produce a composite, high quality version of some information products of interest to the users (or to other, subsequent fusion nodes) at the output.

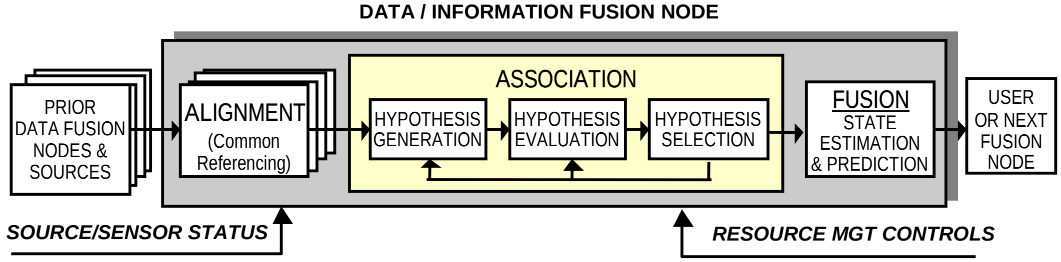

Figure 8: Any data/information fusion node (adapted from [Steinberg, Bowman, White, 1998])

Any data/information fusion node, whatever the fusion level, contains three main sub-processes: fusion, association, and alignment. The means for implementing these functions and the data and control flow among them will vary from node to node and from system to system. Nonetheless, this node paradigm has proven to be a useful model for characterizing, developing, and evaluating fusion systems.

The fusion *per se* actually happens in the *state estimation and prediction* box. The word “state” here refers to the state (actual or estimated) of any situation elements of interest to the users (e.g., target position, velocity, identification, behaviour, intent, threat value, etc.). However, although one can know very well how to combine (or fuse) input elements from different sources to obtain a composite product, data and information alignment and association have to be achieved first before the fusion can be performed.

Data/information related to an entity, a battlefield event, a group, etc., will often be reported independently via a multiplicity of sensors/sources, each differing in coverage area, spectrum, resolution, response time, and observable sensed. Alignment, or common referencing, is the processing of input reports to achieve, among other things, a common time base and a common spatial reference. The alignment sub-process must remove any positional or sensing geometry and timing bias from the data/information. The sub-process also transforms source data into a consistent set of units and coordinates for further processing.

Data association (i.e., that has to do with the management of the uncertainty about the data origin) is a basic fusion process necessary to determine which input data elements correspond to which situation element in the observed situation (for example, whether entity data, which have been reported by different sources, represent the same entity, or different entities).

The diagram of Figure 9 generalizes the concept of a fusion node to the one of a situation analysis node. It also represents a more precise version of such a processing node as it includes the notion of a stored representation of the current knowledge of the world (and its associated management), and the notion of ancillary KID sources that are necessary to the execution of the fusion and inference processes.

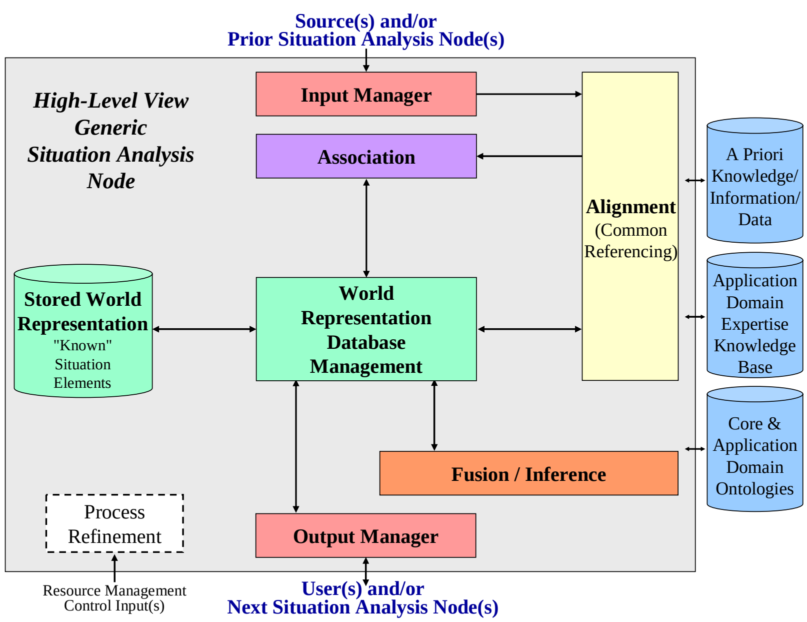

Figure 9: Any situation analysis node

In particular, Figure 9 is a better representation of a situation analysis node as it allows for the easy illustration of the steps and timing for the processing of a user request for information on the current situation (or for a projection of it) as in Figure 10, or for the processing of new input elements (i.e., a situation update) as in Figure 11.

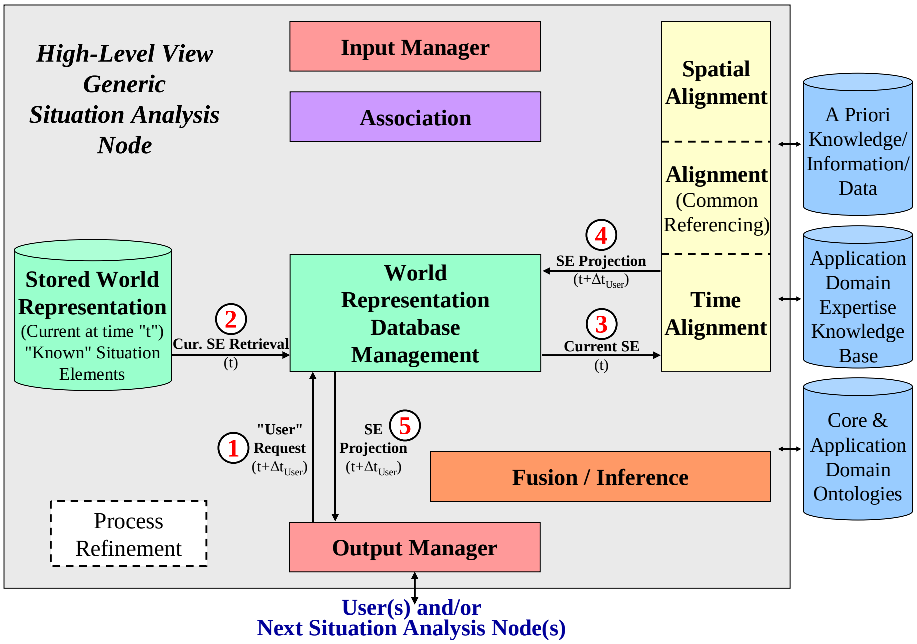

Figure 10: "User" request for "known" situation elements

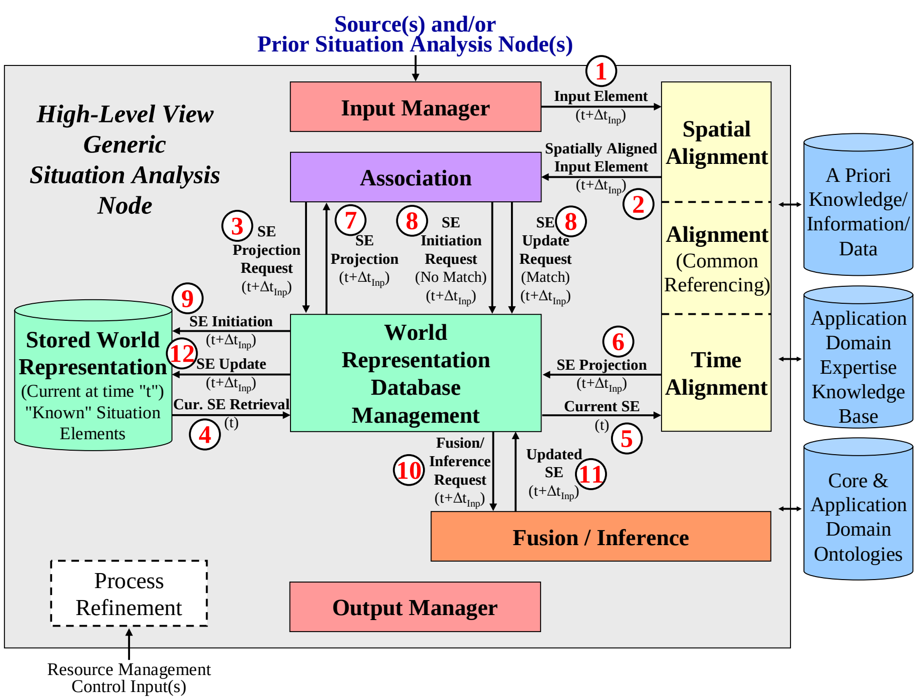

Figure 11: Processing of new input elements (situation update)

4.4 Knowledge/Information/Data Processing Tree

A very important step in the development of any situation analysis or information fusion system is the establishment of the knowledge/information/data (KID) processing tree that explains and illustrates the decomposition (or partitioning) of situation analysis processing into a network of multiple interconnected nodes, going from the sources to the different products relevant and useful to (i.e., required by) the commanders. Such processing trees are shown in Figure 12. There are single-source processing (SSP) nodes, and multiple-source processing (MSP) nodes. An important aspect is the notion of *specific* interfaces ("I") to the sources. The challenge here is to encapsulate most of the specificities of an application domain into interfaces that perform the necessary processing to accept the data and information from the very specific sources on one side, and to provide standardized inputs to generic situation analysis and information fusion engines on the other side.

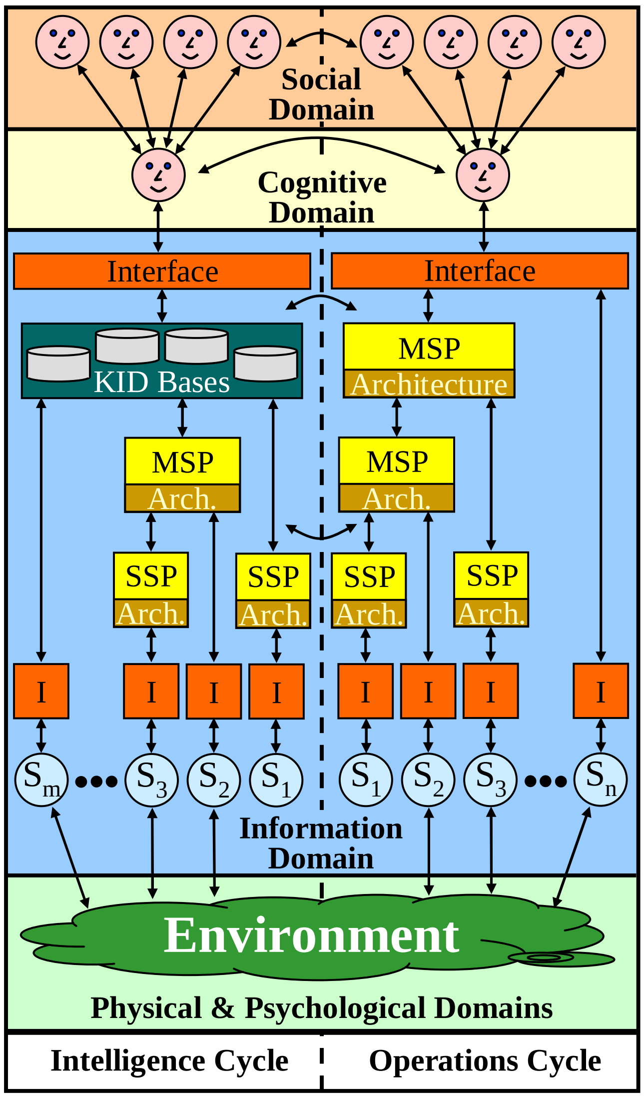

Figure 12: Knowledge/Information/Data (KID) Fusion/inference processing trees

4.4.1 Knowledge/Information/Data Sources

A number of sources provide knowledge, information, and data (KID) to the situation analysis process at a variety of levels ranging from sensor data, to information obtained from databases, to human input. Hence, multiple types of dynamic and static KID are made available to the SA process. Actually, most of the specificities of each application domain come from the relevant specific KID sources to be exploited in this domain. A wide variety of data and information about socio-political/cultural aspects, terrain and weather (geospatial/imagery), military infrastructures and capabilities, civilian infrastructures and resources, intelligence, etc. can be provided by a wide variety of heterogeneous sources that include military sources (e.g., sensors, databases, C2 systems, DND/CF reports & returns, other government sources, coalitions, etc.) and open sources (internet, TV channels, commercial, human, etc.).

All these sources and the KID they provide must be well understood before any appropriate situation analysis or fusion support system can be designed. In particular, the sources must be characterized in term of the quality of the KID they provide, the quantity of KID provided as a function of time, the interface format used (i.e., the KID packaging at the output of the source), etc.

4.5 Adaptive Fusion and Reasoning/Inference

The fusion model proposed by the JDL DIFG, with its process refinement capability, implicitly supposes that all levels of fusion are integrated. This means, for instance, that the level-1 fusion process (object assessment) should be polished and enhanced by leveraging the results of higher levels of fusion (levels 2 and 3). A tight integration is claimed to be essential to gain the maximum benefits from the fusion process.

In this regard, to improve the process of data and information fusion and ultimately that of situation analysis, in a multi-source system, the processing and the resources must be constantly managed and coordinated. This defines the problem of the process refinement or the adaptive fusion. Development of adaptive fusion systems is driven by the belief in the continuous refinement. This essentially concerns the study/implementation of ways to improve and optimize the on-going fusion process. Process refinement closes the loop over all of the fusion levels and, based on the newly available contextual information; it develops options for collecting further information, allocates/directs the resources towards the achievement of the mission goals and/or tunes the processing parameters for the real-time improvement of the effectiveness of the whole fusion process.

Even though it has witnessed a growing interest during the last few years, process refinement, which represents a logical extension of the fusion tree, is still the least mature part of the fusion process. DRDC Valcartier has initiated R&D activities to study the specific problem of integrating all levels of fusion involved in the compilation and the analysis of the situation, and to demonstrate the benefits of the integration. The work undertaken seeks a new formalism, based on the control theory, for making the fusion process adaptive. Therefore, process refinement is currently being addressed from a control theory viewpoint. A framework for integrated fusion composed of a number of interconnected fusion sub-processes or agents has also been proposed.

4.5.1 Resource Management Node

The duality between data fusion and resource management has often been highlighted by the JDL community [Steinberg, Bowman, White, 1998]. This duality can be extended to include the architectures and functionality of data fusion and resource management, leading to the notion of a resource management node, as illustrated in Figure 13.

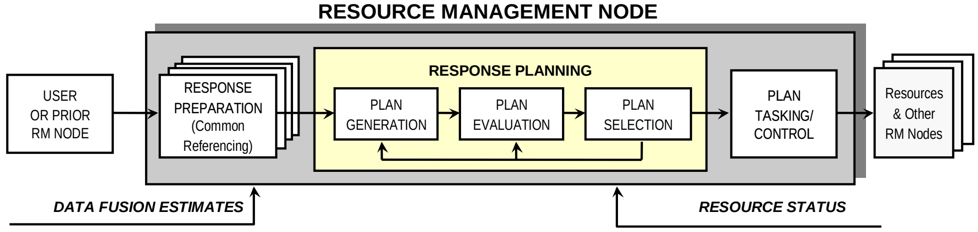

Figure 13: Any resource management node (adapted from [Steinberg, Bowman, White, 1998])

A resource management node involves functions that directly correspond to those of a data fusion node. The common referencing has to do with normalizing performance metrics of the given problem and normalizing performance models of available resources, as well as any control format and spatio-temporal alignment. Plan generation is about the candidate partitioning of the problem into subordinate problems and candidate assignment of resources. Plan evaluation is about evaluating the conditional net cost, and plan selection about determining a decision strategy. Finally, control (i.e., plan execution) is about generating the control commands to implement the selected resource allocation plan.

As multinodal data fusion trees are useful in partitioning data association and state estimation problems, so are resource management trees in partitioning planning and control problems. This is especially important regarding level-4 fusion, or process refinement.

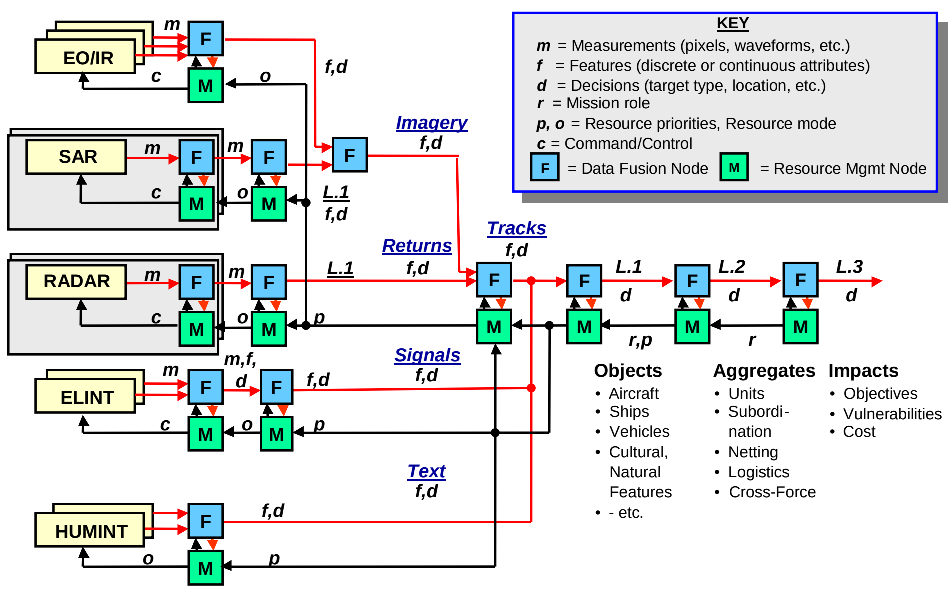

Figure 14: Integrated data fusion/resource management trees ([Steinberg, Bowman, White, 1998])

Diverse system requirements can drive system designers to many different solutions for integrating data and information fusion and resource management (to include process refinement). Figure 14 (from [Steinberg, Bowman, White, 1998]) represents highly integrated fusion/management systems as part of a multi-faceted, spatially distributed, sensor/response system. Such solutions are facilitated by the formal duality between data fusion and resource management, resulting in the analogous processing node paradigms for the two functions. Note that as one moves to the right of interlaced fusion/management trees as depicted in Figure 14, the fusion/management node pairs generally operate with broader perspectives and slower response times.

4.6 Supporting Knowledge/Information/Data

The techniques being developed for information fusion and situation analysis are becoming increasingly more sophisticated, particularly through the incorporation of methods for high-level reasoning processes. A fundamental component of these techniques and methods is a database (or databases) containing knowledge that lists such things as expected objects, behaviour of objects, and relationships between objects [Boury-Brisset, 2001]. A SASS should analyse and combine observations within the context of this a priori knowledge.

The expression “a priori knowledge” used here actually includes static (or slowly changing) knowledge/information/data (KID) to support the various information fusion and situation analysis processes. It refers to different aspects that can be used by situation analysis modules, such as:

- political knowledge/information/data,
- geographical knowledge/information/data,
- application domain expertise knowledge base
- core & application domain ontologies
- complete cases / “situations” base
- platform characteristics,
- mission guidelines,
- weapon characteristics,
- corridors and flight paths,
- lethality,
- emitter characteristics,
- doctrine,
- etc.

The choices made for the design and composition of the databases can be an important factor in the usefulness of the situation analysis processes that they support [Boury-Brisset, 2001]. These choices can also potentially impose critical analysis bottlenecks in the processes and ultimately, they can even represent significant barriers to enhancing these processes.

Traditional support databases are used to store and retrieve large amounts of data that can be accessed efficiently using standard languages (e.g., the SQL language for relational databases) for use by situation analysis algorithms [Boury-Brisset, 2001]. However, databases are limited both in data representation and in capabilities for supporting the situation analysis process.

The expression "a priori knowledge" entails several things. The "knowledge" portion of the expression refers to the fact that the database may contain more than just a description of objects. More abstract notions about the behaviour of these objects, or the relationships between objects can also be included. It is the existence of this different level of information, so important to sophisticated SASS processes, that characterizes the database as containing knowledge, not simply data. The "a priori" portion of the expression entails that the contents of the database are mostly collected, analysed and stored in advance of use in the decision support processes. However, aspects like user modification of the database, or intelligent learning agents that can dynamically add knowledge to the database, also need to be considered.

It thus seems useful to go beyond the basic concept of a support database towards the more advanced idea of a knowledge server. [Boury-Brisset, 2001] discusses research activities to extend the traditional and conventional concept of a support database for information fusion and situation analysis to the one of a Knowledge Management and Exploitation Server (KNOWMES) product. She describes the functional architecture of a KNOWMES that makes use of ontologies and heterogeneous knowledge sources, and also reviews some engineering aspects for its construction. Figure 15 illustrates the KNOWMES concept.

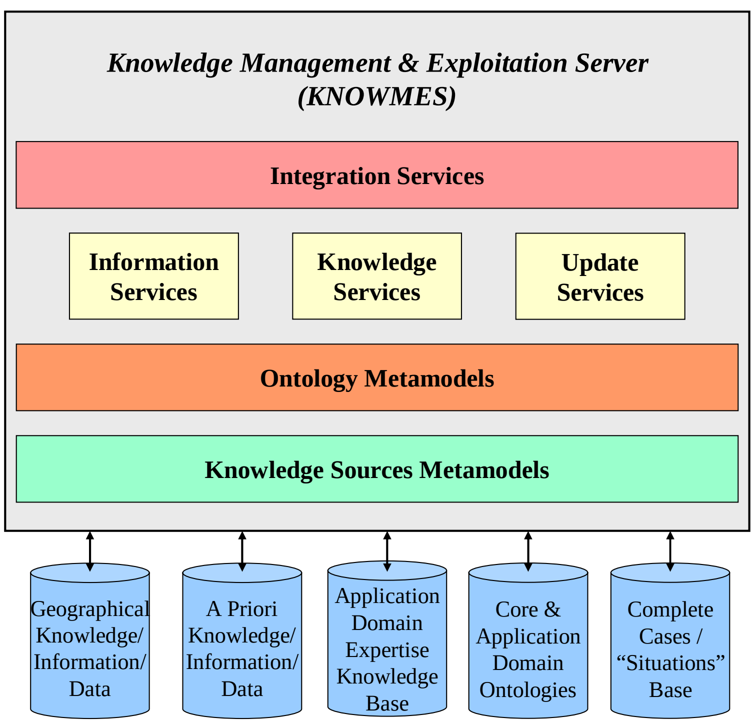

Figure 15: Concept of a knowledge management and exploitation server (KNOWMES)

4.6.1 Application Domain Expertise Knowledge Base

An application domain expertise knowledge base (KB) is the organized repository for the collection of knowledge related to a domain and used for understanding, formulating, and solving problems in a knowledge-based system [Stefik, 1995]. The basic elements that are usually included in the KB are [Turban, Aronson, 1998]:

- facts, such as the problem situation and theory of the problem area,
- special heuristics, rules and hints that direct the use of knowledge to solve specific problems in a particular domain, and,
- global strategies, which can be both heuristics and a part of the theory of the problem area.

Informally, a KB is a set of representations of facts about the world [Russell, Norvig, 1995]. The declarative approach to system building expresses knowledge in the form of sentences. This simplifies the construction problem enormously. Knowledge is contained in computer systems in the form of sentences that are stored in a KB in a knowledge representation language. There must be a way to add new sentences to the KB, and a way to query what is known.

Once a KB is built, AI techniques are used to give the computer an inference capability based on the facts and relationships contained in the KB [Turban, Aronson, 1998]. That is, the KB contains a data structure that can be manipulated by an inference system that uses search and pattern matching techniques on the KB to answer questions, draw conclusions, or otherwise perform an intelligent function. With a KB and the ability to draw inferences from it, the computer can be put to practical use as a problem solver and/or decision assistant. By searching the KB for relevant facts and relationships, the computer can reach one or more alternative solutions to the given problem, in support to the decision makers.

The KB can be organized in several different configurations to facilitate fast inference (or reasoning) from the knowledge [Turban, Aronson, 1998]. The knowledge in the KB may be organized differently from that in the inference engine.

4.7 Knowledge Management

Knowledge management has been briefly discussed in [Roy, 2007]. Building a computer-based system to support the creation, maintenance and sharing of situational awareness and to assist problem solving and decision making will require taking advantage of cutting edge ontology-based knowledge management technologies to provide tools to capture and exploit lessons learned, to make inferences that turn data and assumptions into information, and for data/information classification, categorization, clustering, search, etc. Recent work on contextualized user-centric task-oriented knowledge services (based on web services and portal technologies) will have to be taken into account. Such work is reported in [Gauvin, Boury-Brisset, Auger, 2004], [Gauvin, Boury-Brisset, Garnier-Waddell, 2002], and [Gouin, Gauvin, Woodliffe, 2003].

4.8 Architecture

Architectural issues are an important aspect of any serious development project for a situation analysis support system. Such issues are briefly discussed here.

4.8.1 Information Fusion and Situation Analysis Processing Architecture

The investigation and development of appropriate software architecture to support the implementation and real-time execution of the situation analysis and information fusion techniques per se is of the utmost importance. There is already a lot of effort within DRDC devoted to various system architecture issues, especially to deal with complex systems of systems and their associated interoperability characteristics. The related crucial aspects of information management are also well covered. However, there is a serious gap concerning the implementation and real-time execution on computer-based support systems of the human-like reasoning tasks and processes required for situation analysis and information fusion. An additional challenge concerns the desire for a unified framework for SAIF, i.e., a framework that can account for interactions between people, between machines and between people and machines. This defines the system challenge [Lambert, 2003]: How should we manage data fusion systems formed from combinations of people and machines?

Regarding these issues and challenges, one can view the situation analysis process as a set of numerous dependent and independent sub-processes, or capabilities, at multiple levels of abstraction. Every sub-process can itself be further hierarchically decomposed into multiple sub-processes. These situation analysis capabilities can be regarded as agents (humans or computer-based agents) having some degree of autonomy, each one interacting with its own changing environment that could be the external physical world, or the other agents (i.e., there is a requirement that the situation analysis capabilities must, at a minimum, communicate with one another or, ideally, cooperate with one another). Clearly, these situation analysis capabilities must be integrated and interleaved into an overall processing flow. This view will require the investigation and development of an advanced software architecture suitable for the incremental integration of existing and new SAIF capabilities. Blackboards and multi-agent systems are key computational concepts of computer science that will need to be considered as technological enablers [Corkill, 2005] [Corkill, 2003].

4.8.2 System-of-Systems Integration Architecture

In addition to the development of an approriate architecture to best enable situation analysis and information fusion, there is a need to take care of the system-of-systems integration architecture. This is necessary for the integration of the SAIF capabilities as tools/services in national CCISs, but also when using these capabilities in task groups or coalitions.

The development of an overall C2 support system, including a SASS as one major component, should be based on a service-oriented architecture (SOA) framework providing the foundation of a sound enterprise reference architecture that presents a number of benefits discussed in [Doculabs, 2003]: ability to rapidly adapt to changes in business conditions, ability to reduce the amount of time spent developing custom code, and cost savings as more of an organization's existing investments in technology are leveraged. The end goal of a service-oriented architecture is to provide easy and secure access to enterprise technology and process resources, maximizing re-use and minimizing cost, while improving the performance and reliability of the systems. The organizations involved in the development of an enterprise system can think about a phased approach to the implementation, ensuring the success of the project.

Unlike traditional architecture approaches, the enterprise reference architecture promotes the use of a mechanism for systems to take action when pre-determined or unplanned events arise, such as the failure of a business process to reach completion within a specified timeframe. When considering this additional mechanism, the architecture is said to be event-driven and consequently, more dynamic than non-event driven architectures. For the development of a C2 support system, the implementation of an event driven architecture is truly important in order to ensure a responsive system to the end users during crisis periods. One main challenge about developing a C2 support system is the ability to leverage the many technology infrastructures (hardware and network infrastructures) and application systems owned by the many organizations participating in the development of the enterprise system. To address this challenge, the architecture should provide a clear approach for the integration of and the access to the application systems.

4.8.3 Data Models and Structures

Some specification and structuring of the information is required in order to achieve automated situation analysis and information exchange. From a system perspective, the structure of the information is expressed in a data model, built and documented in accordance with an accepted methodology [MIP, 2003]. Such a model defines the standard elements of information (data).

Trying to create an information structure that represents all of the information about an arena of operations is an understandably complex task. Data modeling methodologies have adopted several conventions that parallel the military staff processes in many ways. Actually, a data model is typically composed of three models, namely the conceptual, logical and physical [MIP, 2003].

The conceptual data model represents the high level view of the information in terms of generalised concepts. This model is of interest to senior commanders wishing to verify the scope of the information structure. The logical data model represents all of the information and is based upon breaking down (or sub-typing) the high level concepts into information that is regularly used. A logical data model specifies the way data are structured with an entity-attribute-relationship diagram and supporting documentation. This model should be of interest to staff officers to ensure that the operational information content is complete. The physical data model provides the detailed specifications that are necessary to generate a physical schema that defines, for example, the structure of a database.

4.9 Human-Computer Interaction

In a C2 environment, the human interface defined by its sensory modalities (such as the visual and auditory sensors) is usually not sufficient to process all of the information required by the decision-making task. A technological interface must thus be designed to support the human in his limitations. The concept of such an interface is shown in Figure 16.

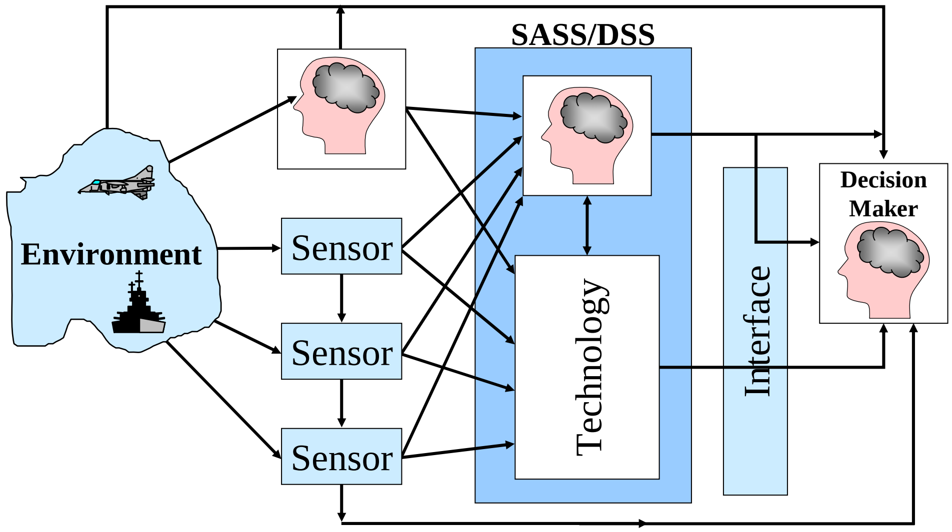

Figure 16: The importance of the support system interface in a complex C2 environment

In many circumstances, most of the information required is made available to the user through such an interface that often becomes the main link between the human and its environment. The decision-maker's SAW is thus highly related to the quality of this interface. Actually, one of the main challenges of the interface is to strongly support the establishment of a cognitive fit between the support system and the decision maker. In an ideal situation, this interface could be seen as an extension of the human visual, auditory and memory capabilities. By properly organizing the information according to the human capabilities, an efficient interface may provide to the decision maker the opportunity to process more of the critical information. Indeed, the ultimate goal of any display design is to positively impact the performance of the human-machine system of which it is a part [Morrison et al, 1997].

To enhance the SAW and decision-making (DM) processes, the critical information required for optimal DM must be presented through the interface, in an appropriate, compatible format with the human information processing. This information must also be presented at the proper time, as the situation unfolds.

Regarding these issues, [Roy, Breton, Paradis, 2001] provide a description of an "operational-like" human-machine interface prototype called CODSI (Command Decision Support Interface). It has been developed as a key component of the experimental environment used to efficiently study the enhancement of SAW quality in computer-based SA and command decision support systems for complex environments such as C2. The main objective with CODSI was not to develop and code "the solution" for a specific interface to a given support system, but rather to develop "a tool" to investigate potential solutions, with maximum flexibility, and with no *a priori* restriction on the interface concepts and technologies to be explored. Many requirements were defined to achieve this objective. Essentially, in addition to providing a capability to adequately convey tactical information to command decision makers, the intent was to supply an appropriate proof-of-concepts test environment to:

- demonstrate and evaluate display concepts derived from cognitive theories and developed from a technological perspective;

- link the effort of the human factors specialists and technological system designers;
- identify which information made available by the technology is required by the decision-maker;
- study and evaluate human-computer interactions concepts for SA and define the best presentation format compatible with the human information processing;
- evaluate the appropriate time to present the information in the situation;
- empirically study human performance in a technological environment (e.g., to support methodologies for SAW measurement);
- demonstrate the enhancement of SAW by computer-based situation analysis and decision-making support systems.

The mutual influence of the human factors and the technological perspectives produces an appropriate vehicle to encourage the exchange of ideas and the identifications of issues between all specialists involved in the design process of a support system.

5. Evaluation in Laboratory Testbeds Using Modeling and Simulation

From a research and development perspective, SASS system developers need capabilities that allow them to assess if a proposed SASS is working properly, as expected. A set of tools is thus required to support the designer/developer/user/operator in quantitatively assessing the performance of the SASS algorithms and techniques.

Rigorously evaluating candidate SASS algorithms using real sources of knowledge, information, or data, along with meaningful measures of performance, is not always practical. For example, real data typically does not include ground truth information, thereby reducing the possibilities of comparing the situation model derived using the support system with the real situation in the environment. Moreover, one often has to face the extremely limited availability of trial data to support algorithm analysis and development, and SASS prototyping. Many research programs cannot afford to incur the additional costs of data collection for the purpose of demonstrating concepts with real data. Alternatives to this situation include artificially synthesizing appropriate data from trial data collected under non-standard conditions (not easy to do in a convincing manner), or to employ sufficiently high-fidelity simulators. This last option has often been retained at DRDC Valcartier for the R&D activities aiming at exploring the level-1 fusion concepts since most of the time, representative simulated data may be adequate to verify or validate such concepts.

A highly modular, structured and flexible simulation environment has been developed as a proof-of-concept demonstrator for multi-sensor data fusion (MSDF) [Roy, Duclos-Hindié, Bossé, 1999]. This simulation environment is called CASE ATTI (Concept Analysis and Simulation Environment for Automatic Target Tracking and Identification). For CASE ATTI, a high fidelity simulator that emulates the behaviour of real targets, sensor systems of the HALIFAX class ships and the meteorological environment has been developed to generate simulated sensor and link data to stimulate the MSDF systems under evaluation. It allows the user to create and edit test scenarios with multiple ships/sensors/targets. The ships can be stationary or moving along predefined paths. One or several sensors can be assigned to each ship. Targets are created with defined trajectories and attributes. In addition to high fidelity stimulation, one of the main requirements of the CASE ATTI test bed has been to provide the algorithm-level test and replacement capability required to study and compare the applicability and performance of advanced, state-of-the-art MSDF techniques.

As mentioned above, CASE ATTI is dedicated to R&D in level-1 fusion. Following the evolution and extension of the R&D program towards higher-level fusion, [Paradis, Roy, 2000] discuss another development at DRDC Valcartier of a modeling and simulation facility, called Simulation Environment for the Analysis of the Tactical Situation (SEATS), for the stimulation and performance measurement of situation analysis agents running on a blackboard architecture.

The SASSs foreseen to support command teams must be real-time systems. The correctness of the final implementation of a real-time system is not only a function of the accuracy of the computations performed by the system, but also a function of the time at which the results of the computations are produced. In this regard, CASE ATTI is a non-real-time proof-of-concept simulation environment. Even though it is a very powerful tool, it does not provide all of the capabilities required to meet the performance assessment needs for MSDF systems. A separate means is thus required to investigate the real-time aspects of the MSDF systems proposed for the future. [Roy, 2000] gives a detailed description of a testbed that would help to establish the real-time requirements of SASSs on speed, responsiveness, predictability, timeliness, etc. At the same time, the proposed testbed would also provide a capability to evaluate various measures of performance for these SASSs.

5.1 Situation Awareness Measurement and Quality Assessment

Progress in information fusion and situation analysis largely depends on the development of a solid body of conceptual and methodological knowledge on how to measure it. The systematic assessment of SA and SAW is a necessary precursor to testing developing theories of SA, exploring factors related to individual differences in SAW, the evaluation of system designs and new training techniques that purport to improve SAW, and a myriad of related issues [Endsley, Garland, 2000].

From a system perspective, rigorously evaluating the performance of SASSs is also of prime importance. The system designer may have several SASS concepts among which to choose in order to fulfill a particular requirement, the SASS may require tuning and optimization to improve performance, or the SASS may be undergoing testing to assure that it is operating correctly.

Unfortunately, no widely accepted scheme for characterizing the performance of SASSs is currently in use. While much research is being performed to develop and apply new SASS algorithms and techniques, little work has been performed to determine how well such methods work or to compare alternative methods against a common problem. [Roy, Bossé, 1995] describes such a scheme (or methodology), initially proposed for MSDF systems, that could be used for SASS performance evaluation using computer simulations. The performance evaluation methodology described in [Roy, Bossé, 1995] provides an appropriate framework to guide the system designers in the evaluation of current and future SASSs suitable to fulfill the Canadian Forces requirements and in the optimization of the operation of these systems to obtain the best performance.

5.2 Stimulation Capabilities for the SASS Applications

A stimulation module must provide realistic input knowledge, information, and data (KID) to the SASS (in a way similar to the way they would typically be provided by the actual external sources) in order to allow the end user to evaluate the performance of this SASS in representative conditions. As the use of real source KID is often impractical, high-fidelity simulations should be used instead.

5.3 Performance Evaluation Capabilities

A performance analysis database (PADB) should contain an archive of all the KID manipulated by the laboratory testbed. The main purpose of the performance evaluation (PE) module is to provide a capability that allows the end user to assess if the SASS is working properly, as expected. The PE module should thus comprise a set of tools to support the designer/user/operator in his/her quantitative assessment of the performance of the SASS algorithms and techniques. These tools should include a compilation mechanism for the situation analysis statistics, computation mechanisms for the various measures of performance, etc.

6. Field Demonstrations and Experiments

A user-centric approach and work plan for a complete SASS development program must include field experiments, as such a program is typically directed towards the validation of concepts, technologies and situation analysis processes, in order to provide both timely and directed systems input to military planners and acquisition managers. The project partners coming from the operational communities should participate in technological demonstrations and experiments for the evaluation and validation of the resulting system during some exercises, demonstrations, or experiments to be identified and/or defined with them. The project plan should propose both interim and full-scale technological demonstrations and experiments of the science and technology, and the capability and knowledge of the project partners. During the final experiment, the real impact of the SASS on the end-users should be assessed with a deployed and completed situation analysis support capability that should be accessed by all of the project participants and stakeholders, for end-user experimentation with the system, to achieve significant validation and testing. These demonstrations/experiments, including the requisite training and technology transfer, should be carried out by the project team, including end-user organizations, using facilities provided by operational units and agencies.

The term experimentation arises from the Latin, experiri, which means, "to try" [Alberts et al, 2002]. A dictionary definition of experiment is a test made "to determine the efficacy of something previously untried," "to examine the validity of a hypothesis," or "to demonstrate a known truth."

Discovery experiments involve providing novel systems, concepts, organizational structures, technologies, or other elements in a setting where their use can be observed and catalogued [Alberts et al, 2002]. The goals of discovery experiments are to identify potential military benefits, generate ideas about the best way for the innovation to be employed, and identify the conditions under which it can be used (as well as the limiting conditions – situations where the benefits may not be available). In a scientific sense, these are "hypothesis generation" efforts. They will typically be employed early in the development cycle. While these experiments must be observed carefully and empirically in order to generate rich insights and knowledge, they will not ordinarily provide enough information (or evidence) to reach a conclusion that is valid (correct understandings of the cause-and-effect or temporal relationships that are hypothesized) or reliable (can be recreated in another experimentation setting). They are typically guided by some clearly innovative propositions that would be understood as hypotheses if there were a body of existing knowledge that supported them. Typical discovery experiments lack the degree of control necessary to infer cause and effect, and often involve too few cases or trials to support valid statistical inference. However, these limitations are not barriers to discovery experimentation. Most new concepts, ideas, and technologies will benefit from discovery experimentation as a way of weeding out ideas that simply do not work, forcing the community to ask rigorous questions about the benefits being sought and the dynamics involved in implementing the idea, or specifying the limiting conditions for the innovation. Good discovery experiments will lay the foundation for more rigorous types of experiments where the hypotheses they generate are subject to more rigorous assessment and refinement. Moreover, discovery experiments must be observed in detail if they are to reach their maximum value.

Hypothesis testing experiments are the classic type used by scholars to advance knowledge by seeking to falsify specific hypotheses (specifically if…then statements) or discover their limiting conditions [Alberts et al, 2002]. They are also used to test whole theories (systems of consistent, related hypotheses that attempt to explain some domain of knowledge) or observable hypotheses derived from such theories. In a scientific sense, hypothesis testing experiments build knowledge or refine our understanding of a knowledge domain. In order to conduct hypothesis testing experiments, the experimenter(s) create a situation in which one or more factors of interest (dependent variables) can be observed systematically under conditions that vary the values of factors thought to cause change (independent variables) in the factors of interest, while other potentially relevant factors (control variables) are held constant, either empirically or through statistical manipulation. Hence, results from hypothesis testing experiments are always caveated with ceteris paribus, or "all other things being equal." Both control and manipulation are integral to formulating hypothesis testing experiments.

Demonstration experiments, in which known truth is recreated, are analogous to the experiments conducted in a high school, where students follow instructions that help them prove to themselves that the laws of chemistry and physics operate as the underlying theories predict. Military equivalent activities are technology demonstrations used to show operational organizations that some innovation can, under carefully orchestrated conditions, improve the efficiency, effectiveness, or speed of a military activity. In such demonstrations, all the technologies employed are well-established and the setting (scenario, participants, etc.) is orchestrated to show that these technologies can be employed efficiently and effectively under the specified conditions. Note that demonstration experiments are not intended to generate new knowledge, but rather to display existing knowledge to people unfamiliar with it. The reasons for empirical observation change to recording the results reliably and noting the conditions under which the innovations were demonstrated in demonstration experiments. Failure to capture this information will lead to unrealistic expectations and inappropriate applications of the innovations. This has happened more than once when capabilities developed for a specific demonstration were transferred to a very different context and failed because they had not been properly adapted. Some demonstration experiments involve control, but no manipulation.

[Alberts et al, 2002] takes a deeper look into the anatomy of an experiment: the structures, processes, procedures, and products needed to make an experiment a success. They provide an end-to-end review of an experiment, from its formulation to the delivery of its products. Figure 17 shows an overview of the three major phases in any experiment: pre-experiment, conduct of the experiment, and post-experiment.

The outputs of the pre-experiment phase provide "what we know" and "what we think" as expressed in the experiment model and experiment propositions in hypotheses, and "what we are going to do" as expressed in the detailed experiment plan [Alberts et al, 2002]. The output of the conduct phase is simply the empirical data generated by the experiment as well as other observations and lessons recorded. The output of the post-experiment phase is a revised model that captures and incorporates what is learned, empirical data that others can use, the documentation of supporting experimentation activities, and other findings and conclusions such as lessons learned.

Unfortunately, there is a misperception that most of the effort required in successful experimentation occurs during the actual conduct of the experiment (the most visible part, when subjects are being put through their paces or the experimentation model or simulation is running). In fact, the bulk of the effort in successful experiments is invested before the experiment itself is conducted, in the pre-experiment phase. Moreover, substantial effort is also required after the experiment is conducted when the results are analysed, understood, extrapolated, documented, and disseminated.

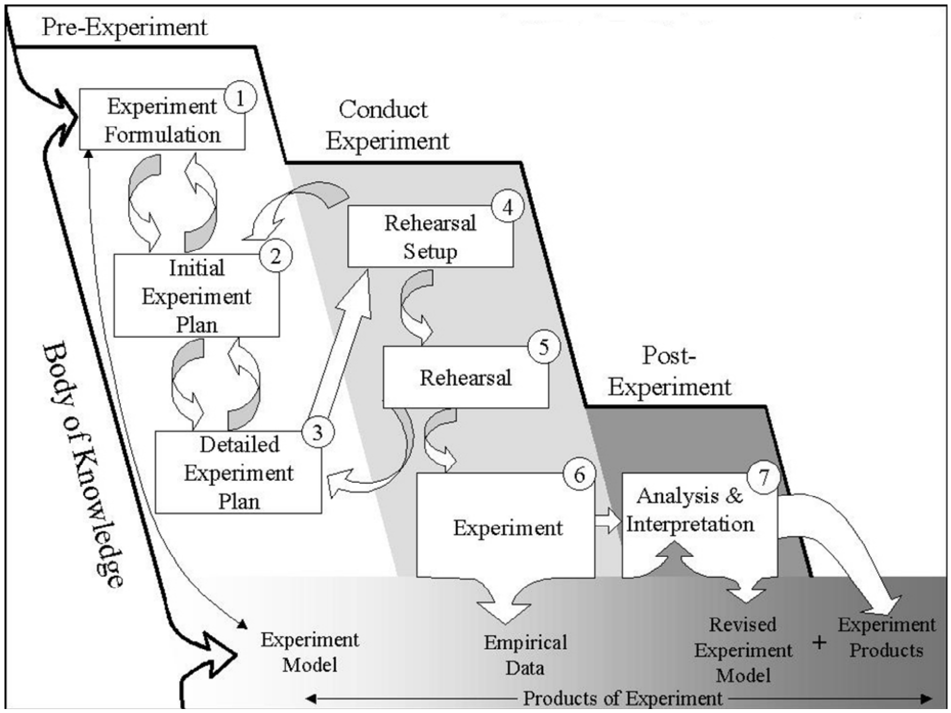

Figure 17: Phases of experiment [Alberts et al, 2002]

This weak grasp of the required allocation of effort across the various elements of the experimentation process often creates mischief by mismatching resources against the work needed to produce quality results. Hence, [Alberts et al, 2002] looks at the whole process from the perspective of the experimentation team, identifies all of the critical steps, discusses their interrelationships, and asks what must be done in order to achieve success. While the detailed discussion of each phase is largely from the perspective of a hypothesis testing experiment, all of these steps are also needed in both discovery and demonstration experiments.

6.1 Demonstration and Experimentation Activities

The activities below, sequentially progressing from a workshop to a large-scale field experiment, should be conducted with the end users to validate the findings and results of the system development program.

Activity 1 – Organize and conduct a workshop involving key organisations and personnel identified by the project sponsor to pinpoint critical issues, processes, etc., through short scenario-based case studies.

Activity 2 – Participate in a major existing experiment/exercise to capture domain specific operational requirements and demonstrate initial prototype functionalities.

Activity 3 – Participate in an exercise aimed at developing the target operational architecture (concepts, sources, organisations, business processes) and demonstrate the initial capabilities.

Activity 4 – Conduct simulation-based, combined laboratory tests aimed at validating functionalities supporting the C2 process.

Activity 5 – Conduct a Limited Objective Experiment (LOE) to capture and validate functional and operational requirements for the development of advanced situation analysis support and knowledge exploitation tools.

Activity 6 – Evaluate and measure within a suitable experimental context the validity and effectiveness of the situation analysis support and knowledge exploitation tools provided.

6.2 Results Analysis

Contrary to popular belief, the experiment is not over when the subjects go home and the VIPs leave armed with a “hot wash” briefing or later with the issuance of a “quick look” report. Several meaningful steps remain to be taken after the conduct of the experiment in order to ensure its success. These key tasks include [Alberts et al, 2002]:

- data analysis;
- integrating experimentation results from different sources and perspectives,
- interpretation of the data and information gathered to generate knowledge,
- circulation of draft results for comment and constructive criticism,
- modeling and simulation to validate and expand findings,
- revision of the products to incorporate the responses to the draft and the new knowledge generated by modeling and simulation,
- archiving experimentation data and materials, and,
- circulating the final products.

All too often, “defeat is snatched from the jaws of victory” after an experiment because too little time and too few resources have been allocated to complete these tasks and exploit the empirical data that has been generated by turning them into contributions to the body of knowledge. One of the most common problems is the desire for instant results leading to a hot wash at the end of the conduct phase of an experiment, a quick look at the results a few weeks later, and a final report that is a shallow discussion of the findings reported in these early products.

This excessive focus and attention given to early deliverables leads to an unhealthy concentration on the immediately measurable and anecdotal evidence [Alberts et al, 2002]. They are a legacy from training exercises where the purpose is prompt feedback in a well-understood problem set. This approval does not reflect an understanding of the complexity of experimentation. Hence, it undercuts the process of experimentation and reduces the impact of experimentation on research and development programs. This does not relieve experimentation teams of their obligations to plan experiments that generate results as promptly as is practical, but it does speak to the problem of post-experimentation efforts and the need to exploit experiments as much as possible.

The most obvious effort of the post experiment phase is analysis. This should be guided by the analysis plan developed as part of the detailed experiment plan. The nature of the tools and processes involved are discussed in detail in [Alberts et al, 2002]. However, a few guiding principles should be noted here.

First, the ideal analysis plan involves a *set* of analyses, not a single analysis. This is a reflection of the fact that a variety of different data (subject background, skill proficiency, behavioural data, survey information, insights from debriefings, etc.) must be analysed, but also a recognition that different analytical tools may be appropriate in order to understand the experiment results richly. The experimentation team needs to think about the “so what?” of an analysis to make sure that it is needed and properly conceived. That is, they need to reflect upon the results of the analysis and the story that would be told to explain the results. Would it make sense? Would it be credible? Would the analysis, as envisioned, support the purpose of the experiment?

Second, the appropriate set of analyses will vary with the purpose and focus of the experiment. Discovery experiments will require open-ended tools and techniques that allow the analysts to explore weakly structured problems and unearth patterns they might not have initially anticipated. Hypothesis testing experiments will require rigorous tools and techniques that permit specific inferences and allow for statistical control of intervening variables. These should also be supported by approaches that allow for the discovery of unanticipated patterns and exploration of ideas emerging as insights. Demonstration experiments, on the other hand, should be primarily supported by analyses that confirm their underlying postulates. However, even these experiments should not be reduced to mechanical calculations that fail to look for new insights, discovery of new limiting conditions, or recognition of novel patterns.

Third, analyses, like experiments, should avoid *single points of failure*. Each analyst or analytical team should be required to show their results and explain them at internal team meetings. Key findings should be deliberately replicated, preferably by an analyst who did not perform the first run. Tests for statistical bias and technical errors should be used (for example, the impact of outlying cases or other distribution problems, the presence of multi-colinearity, or the absence of homoscedasticity) to ensure the results are not an artefact of the analytical processes chosen.

Finally, items of interest from the experiment outside the analysis plan, such as insights coming from participants or anomalies arising from equipment failures, should not be ignored. Senior analysts should work to develop specific approaches, tools, or techniques that allow unanticipated issues and evidence to be understood and exploited to enrich the results.

6.3 Results Communication

The delivery of the knowledge resulting from a SASS development and evaluation project should be accomplished by various and efficient means. Regarding the S&T aspect, publication of papers in seminars and symposia should be done regularly during the execution of the project. The project team should identify early conferences, journals and symposia for publishing the S&T knowledge generated.

One strength of an integrated project team is that it typically includes partners that play an operational role. In the project, they act both as providers of data, information and knowledge, and as clients of the prototype. The knowledge, expertise, system architecture and design should thus be directly and constantly transferred to the main partners of the project. In turn, they should share results with other members of the operational communities. The project requires the participation of all team members. Hence, the knowledge receptors, which will play an active role throughout the overall project, will greatly enhance their receptivity (and their capacity to assimilate the concepts and products) of the acquired knowledge resulting from the project.

Finally, the project team should also work in close collaboration with the knowledge management groups of the end-user and sponsor organizations for the dissemination of the knowledge resulting from the project.

7. Expert System Development

The development of an expert system (ES) involves the construction of the knowledge base through knowledge acquisition from experts or documented sources [Turban, Aronson, 1998]. Determining appropriate knowledge representations is performed during this activity. Other development activities include the construction (or acquisition) of an inference engine, a workplace, an explanation facility, and any other required software, such as interfaces.

At a very high level, the general stages in the development of an expert system are as follows [Giarratano, Riley, 1998]:

- The knowledge engineer first establishes a dialog with the human expert in order to elicit the expert's knowledge.
- The knowledge engineer then codes the knowledge explicitly in the knowledge base.
- The expert then evaluates the expert system and gives a critique to the knowledge engineer.
- This process iterates until the system's performance is judged by the expert to be satisfactory.

[Turban, Aronson, 1998] present a detailed discussion of the development life cycle for an expert system. Table 1 summarizes this cycle. Note that most of the elements of Table 1 actually apply to any software development project; the elements that are specific to the development of an expert system are highlighted in italic.

Table 1: Expert system development life cycle [Turban, Aronson, 1998]

Phase I: Project initialization	• Problem definition
	• Need assessment
	• Evaluation of alternative solutions
	• *Verification of an expert system approach*
	  o *Requirements for ES development*
	  o *Justification for ES development*
	  o *Appropriateness of the ES*
	• Consideration of managerial issues

Phase II: System analysis and design	• Conceptual design and plan
	• Development strategy and methodology
	• *Sources of knowledge / Selecting an expert*
	• Software selection
	  o Software classification: technology levels
	  o *Expert system shells and environments*
	• Hardware support
	• Feasibility study

	• Cost-benefit analysis
Phase III: Rapid prototyping and a demonstration prototype	• Building a small prototype • Testing, improving, expanding • Demonstrating and analyzing feasibility • Completing design
Phase IV: System development	• *Building/completing the knowledge base* • *Testing, validating, verifying, and improving the knowledge base* • Planning for integration
Phase V: Implementation	• Acceptance by users • Installation, demonstration deployment • Orientation, training • Security • Documentation • Integration, field testing
Phase VI: Post implementation	• Operation • Maintenance and upgrades • Periodic evaluation

How should it be determined whether the program solves problems correctly? The developer might compare the answers that a system gets with answers worked out manually [Stefik, 1995]. He/she could increase confidence in this approach by analyzing answers to the smaller sub-problems. He/She might also compare the program's answers to published answers, or check the answer for internal consistency. These different approaches honour different “gold standards” or measures of the quality and performance of the knowledge and the knowledge-based system.

Test cases are a key to refining a system [Stefik, 1995]. Alternative bodies of knowledge can be tested against the same cases to see which versions perform best. Test cases also can be used to check stability of performance as a system is updated. After a system builder extends a knowledge-based system to perform on new cases, he/she can test whether the changes introduce bugs on older cases.

7.1 Expert System Development Team

Table 2 distinguishes the main roles for the participants in the development team for an expert system.

Table 2: Expert system development team participants

The customer	Recognizes the benefits of developing the expert system and is willing to fund its development.
The users	Understand what problem is to be solved.
The domain expert	Has advice on how to solve the problem.
The knowledge engineer	Understands and applies the theory and technology of knowledge-based systems.
The software engineer / architect and/or information system analyst	Knows and applies the best engineering practices for developing software. He/she is especially important if there is a need to interface with other computer programs.
The programming staff	Code the system using appropriate tools and programming languages.

The difference implied between the expert and the user is in the degree of experience [Stefik, 1995]. In any real situation, the user and the domain expert may be the same person or people may have overlapping roles. Notice that the user may, or may not be, the customer. In a large project, there may be a division of technical responsibility between a knowledge engineer, a software engineer/architect and/or information system analyst, and other programming staff.

The key issue is that the system is built by a collaborative team, working together [Stefik, 1995]. A team approach is needed when there is a division of skills for building a knowledge-based system. There is a requirement for communication among the participants. In the development process, the development team will eventually use specific techniques to identify and articulate the knowledge to be represented explicitly in the system.

7.2 Stages in Participatory Design

[Stefik, 1995] discusses stages in participatory design of a knowledge-based system. These are listed in Table 3.

Table 3: Stages in participatory design of a knowledge-based system [Stefik, 1995]

Identification	The project participants establish common ground and engage in conversations about their goals for a knowledge-based system and the necessary background. This stage includes the identification of users and domain experts. During this stage, the participants identify the general problem and begin to create a set of shared, externalized vocabulary for describing the task. This vocabulary is what one calls the common ground. Theoretical foundations for this come from social psychology. The external symbols are non formal project notes.

Conceptualization	A broad framework for the task is developed. During this stage, the participants develop a shared, external model of how the task is done, i.e., the processes of problem solving. Theoretical foundations for this come from information-processing psychology. The external symbols may be semiformal.
Formalization	Protocol data and other evidence are used to develop a formal representation of the task. During this stage, the participants create a more complete model of the detailed steps. Theoretical foundations for this come from search theory.
Implementation	Develop an operational prototype of a knowledge-based system. Implementation decisions are made. During this stage, the participants develop a computationally based model of the knowledge of the task. Theoretical foundations for this come from computer science. The external symbols become formal.

7.3 Expert System Development Tools / Shells

The process of developing expert systems can be lengthy [Turban, Aronson, 1998]. Many tools are available that are designed to expedite the construction of expert systems at a reduced cost. An expert system tool is a language plus associated utility programs to facilitate the development, debugging, and delivery of application programs [Giarratano, Riley, 1998].

Such a tool that is often used to expedite development is called the expert system shell [Turban, Aronson, 1998]. Expert system shells are special-purpose tools designed for certain types of applications in which the user must supply only the knowledge base [Giarratano, Riley, 1998]. That is, they include all the generic components of an expert system, but they do not include the knowledge.

While languages such as LISP and PROLOG are also used for symbolic manipulation, they are more general purpose than expert system shells [Giarratano, Riley, 1998]. This does not mean that it is not possible to build expert systems in LISP and PROLOG. However, it is more convenient and efficient to build large expert systems with shells and utility programs specifically designed for expert system building. Instead of “reinventing the wheel” every time a new expert system is to be built, it is more efficient to use specialized tools designed for expert system building rather than general purpose tools.

Expert systems can thus be developed from scratch (custom made), or they can be purchased as ready-made (off-the-shelf) packages [Turban, Aronson, 1998]. Examples of expert system development products are listed in Table 4.

Table 4: Expert system development products

CLIPS	Public domain software
JClips — CLIPS for Java	Public domain software

FuzzyCLIPS	Integrated Reasoning Group, Institute for Information Technology, National Research Council of Canada.
Jess	Sandia National Laboratories
FuzzyJ / FuzzyJess / FuzzyJ Toolkit	Integrated Reasoning Group, Institute for Information Technology, National Research Council of Canada.
G2	Gensym
ILOG JRules	ILOG
Expert System Designer	Optimal Solution Software
EZ-Xpert	AI Developers, Inc.
GoldWorks III	Gold Hill
ART	Inference Corporation
ART*Enterprise*	MindBox
KEE	IntelliCorp
Rulemaster	Radian Corp.

7.4 Expert System Development Difficulties

Formalizing the knowledge of experts is not simple [Giarratano, Riley, 1998]. In this line of thought, some development difficulties of expert systems are [Turban, Aronson, 1998]:

- Knowledge is not always readily available.
- Expertise can be hard to extract from humans.
- The approach of each expert to situation assessment may be different, yet correct.
- It is hard, even for a highly skilled expert, to abstract good situational assessments when under time pressure.
- Most experts have no independent means of checking whether their conclusions are reasonable.
- The vocabulary, or jargon, that experts use for expressing facts and relations is often limited and not understood by others.
- Help is often required from knowledge engineers who are rare and expensive, a fact that could make the construction of an expert system costly.
- Knowledge transfer is subject to a host of perceptual and judgemental biases.

7.5 System Evolution

A knowledge-based system is usually constructed for use in a particular situation [Stefik, 1995]. In practice, even situations that we think of as being static evolve over time. Knowledge-based systems cannot stand still. As a situation changes, knowledge-based systems need to accommodate with new behaviour often based on new knowledge.

8. Conclusion

When adopting a knowledge-centric view of situation analysis, a corresponding well-structured development process needs to be defined and followed to build appropriate knowledge-based SASSs. Combining elements of information fusion and knowledge-based systems, this report presented a holistic approach and framework, including some recommended high-level steps, for the overall development and evaluation of any knowledge-based SASS. Emphasis was given to the knowledge-centric aspects of the approach.

The report didn't present "solutions", or findings and results of completed activities. The intent was more to provide a fair description of a suitable development approach, in order to contribute to setting up a foundational R&D framework for two projects that are just starting under the Applied Research Program (ARP) at Defence R&D Canada: SATAC and CKE-4-MDA. Among other things, expert system development and cognitive, software, knowledge and ontological engineering were discussed.

SAIF has a critical role to play in the C2 and intelligence processes. For this reason, numerous ongoing DND and DRDC projects have an important SAIF component. However, despite the importance given to SAIF in many DND strategic documents and projects, the current systems and the associated technology often fail to meet the demanding requirements of the operational decision makers; major science and technology advancements are required to really achieve the full potential of the related enabling technologies and to best serve the operational communities. The effort reported here is one step in this direction; it contributes to the establishment of some solid basis on which a long-term R&D program should be built.

Clearly, adopting a knowledge-centric view of SAIF and developing a complete support system along the approach and framework presented here is a very challenging, multidisciplinary enterprise. Project teams will certainly have to seriously deepen the aspects described in this report along the way. Along this line of thought, R&D activities have been and are still currently being conducted to further investigate knowledge representation concepts, paradigms and techniques [Roy, Auger, 2007-B], and reasoning processes, methods and systems [Roy, Auger, 2007-C] for use in knowledge-based SAIF support systems. Adopting the knowledge-centric view of SAIF requires that knowledge (i.e., expertise) be eventually acquired from the subject matter experts (SMEs) of the different military and public security application domains. In this regard, knowledge and ontological engineering techniques have been and are still being investigated [Roy, Auger, 2007-A]. Knowledge acquisition and validation sessions with SMEs are about to be conducted.

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Annex A Capture of SASS Requirements – Statement of Work Example

This annex provides an example of a statement of work (SOW) that could be used within a contract to capture and document the requirements for a situation analysis support system (SASS) in a specific domain. The intent of this contract is to achieve this objective based on combining cognitive and software engineering methodologies into an integrated approach that shall lead to the identification of user needs, problems and deficiencies, etc., in the form of explicit requirements. In the example provided here, one intends to conduct this activity for a project on situation analysis for the tactical Army commander (SATAC). However, this example could be tailored to any project with aiming to develop a SASS for some decision makers.

A.1 Contract Objectives

An objective of this contract is to identify and document the cognitive requirements related to the situation analysis activities of the tactical commanders of the Canadian Army when they are involved in the highly dynamic and complex situations typical of full-spectrum operations scenarios. The contractor shall also identify the system and software requirements for the development of a knowledge-based situation analysis support system (SASS) for these tactical commanders engaged in such operations.

A.2 Overall Contractual Elements

The contractor shall:

- Conduct cognitive and software engineering analysis and design activities regarding situation analysis for the tactical Army commander (SATAC), using formal approaches.
- Conduct these activities in the context of a Full-Spectrum Operations (FSO) scenario, representative of those relevant for the SATAC, and that provides specific events and delineates essential/critical aspects relevant to the situation analysis process for the tactical Army commanders. The Scientific Authority will provide this scenario to the contractor as Government Furnished Information (GFI) upon contract award.
- Conduct the analysis activities from a revolutionary perspective instead of an evolutionary perspective. That is, the contractor shall conduct the unrestricted exploration of concepts, with the only goal to maximize efficiency.
- Seek opportunities to exploit Army training facilities for the analysis and design activities, whenever appropriate and feasible.
- Generate a set of artefacts (corresponding to the deliverables of this contract) that, taken together, shall provide a coordinated set of analysis, design, and evaluation of innovative support concepts for SATAC.

- Enforce rigour and traceability regarding how the knowledge of the tactical Army commanders is derived and documented, for the artefacts to be produced, and for the requirements being identified.
- Select and use an appropriate CSE/SE analysis and design tool (or set of tools) to support the contract activities and to produce and maintain different versions of the necessary artefacts.
- Apply the main principles of CSE that are relevant to this effort while conducting the design activities of this contract.

A.3 Work Phases

The tasks planned for this contract and described below have been partitioned into three phases:

- Phase I – Work Domain Analysis
- Phase II – Development of Visualization and Support Concepts
- Phase III – System and Software Requirements

A.4 Detailed Statement of Work & Work Plan

The contractor shall perform the tasks below in order to fulfil the aforementioned objective of this contract.

A.4.1 Phase I – Work Domain Analysis

The contractor shall conduct the various tasks and analysis activities described below in order to study and document the work domain of tactical Army commanders, with a particular focus on situation analysis.

<u>Task 1 – SATAC Domain Knowledge Acquisition from Documents</u>

The capture and understanding of the requirements of the tactical Army commanders regarding situation analysis can be initiated through reading appropriate documentation of the domain. At contract award, the Scientific Authority will thus provide the contractor with reference documents about relevant topics. The document set will potentially include many document types: strategic vision, force development, concepts of operations (CONOPS), doctrine, scenarios, lessons learned, training documentation, documented situation analysis processes, and technical reports.

The contractor shall review and analyse this documentation in order to achieve and document an initial insight into the concepts, the current status and context, and the likely evolution of situation analysis for the tactical Army commanders (SATAC).

A particular attention shall be devoted to the results and findings of prior studies that:

- were recently conducted for the Army,
- cover relevant aspects for the tactical Army commanders,

- have a content related to situation analysis,
- have a cognitive analysis content,
- establish the state of the art regarding support technologies for SATAC

The contractor shall discuss how these results and findings could be exploited in SATAC.

The contractor shall document in a report, entitled “Initial Assessment of Situation Analysis for the Tactical Army Commanders”, the work performed under this task, along with the corresponding findings and results.

The contractor shall use the reference documents not only to produce the initial assessment of SATAC mentioned above, but also during the overall execution of the contract, to support the other tasks described next.

<u>Task 2 – SATAC Domain Glossary</u>

The contractor shall capture and document in a glossary a common vocabulary for SATAC, i.e., the important and common terms and concepts that frequently and consistently come up when discussing the Canadian Forces (CF) Army and the activities of the tactical Army commanders, especially regarding situation analysis. Each term shall have a clear, concise, and unambiguous definition, and all stakeholders should agree on these definitions (i.e., the contractor shall document a consensus agreement on the meaning of the terminology used).

The glossary shall be continually refined throughout the contract, as new terms and concepts are identified and existing ones are better understood. It is especially important that the contractor consistently use that vocabulary throughout the contract to reduce misunderstandings among the project team members.

<u>Task 3 – Planning for Knowledge Acquisition from Tactical Army Commanders</u>

This contract requires business modeling activities (Task 5) and cognitive system engineering analyses (Tasks 6-9) of the work domain of the tactical Army commanders. To support all these tasks, the contractor shall conduct, in parallel, SATAC domain knowledge acquisition activities with subject matter experts (SMEs). These domain experts shall be various stakeholders of the Canadian Forces (CF) Army such as end users (i.e., tactical Army commanders), customers, managers, funding authorities, product champions, etc., as identified with the Scientific Authority.

In Task 3, the contractor shall propose a methodological approach and generate a plan and a schedule for the conduct of the knowledge acquisition activities mentioned above. The contractor shall work with the Scientific Authority and arrive at the best plan given availability constraints of the SMEs and the data collection needs for the business modeling and cognitive system engineering analyses. Taking into account knowledge acquisition opportunities, the plan shall be a combination of the following types of activities (whenever relevant and feasible):

- Formal interview sessions with the SMEs. Among other things, such sessions shall include discussions with SMEs on the business model (Task 5) and the functional abstraction network (FAN) model (Task 6) and their gaps in modeling the SATAC domain, and also on difficult scenarios and how they impact the situation analysis process.

- Attendance to warfare courses relevant to SATAC.
- Attendance/participation to various events (e.g., Army simulation and training exercises) at different Army training facilities.

As a minimum, the plan shall include two formal interview sessions with the SMEs, at sites yet to be determined. Current tentative dates for these sessions are the 7th week after contract award and the 13th week after contract award. Finally, the plan shall also include elements for the development, as part of Task 4, of specific scenario components directly supporting the knowledge acquisition activities with the SMEs and in line with the Full-Spectrum Operations (FSO) scenario initially provided.

The contractor shall document in a report, entitled "Tactical Army Commander Knowledge Acquisition Plan", the work performed under this task, along with the corresponding findings and results.

Task 4 – SATAC Domain Knowledge Acquisition from Tactical Army Commanders

The contractor shall conduct SATAC domain knowledge acquisition activities with subject matter experts, according to the proposed methodological approach and the plan previously defined in Task 3.

The contractor shall conduct at least two formal interview sessions with the SMEs (cf. Task 3). Prior to these sessions, and in order to better achieve the objectives of this task, the contractor shall develop and document scenario components in line with the FSO scenario initially provided, and directly supporting the knowledge acquisition activities with the SMEs. The contractor shall record on video the specific information-gathering activities, whenever appropriate and if possible, for subsequent reference.

Task 4 shall be performed, in an iterative and participatory manner, in parallel with the modeling and analysis activities of Tasks 5-9, in order to supply these tasks with the required domain knowledge, and to "operationally" validate (or invalidate) the analytical findings. Reciprocally, as interim results from the modeling and analysis tasks become available, they shall be used as support material for further knowledge acquisition with the SMEs.

While conducting this task, the contractor shall expand the SATAC domain glossary (cf. Task 2) with a common vocabulary, i.e., the important and common terms and concepts that frequently and consistently come up during the knowledge acquisition activities with the tactical army commanders.

The contractor shall document in a report, entitled "Situation Analysis Knowledge Acquisition from Tactical Army Commanders", the work performed under this task, along with the corresponding findings and results.

Task 5 – Business Model of the Tactical Army Commander Organization

Based on the initial knowledge of SATAC acquired in Task 1 from various documents, and provided along the way with additional knowledge from SMEs (through Task 4), the contractor shall identify and document the processes, roles, responsibilities, element interactions, etc. of the organization of the tactical army commander (TAC) in a model of the relevant subset of the CF Army business. This business model shall comprise a business glossary, a target-organization assessment, a business vision, the business rules, a business use-case model, a business object model, and the supplementary business specifications.

In particular and more precisely, the contractor shall:

- Expand the SATAC domain glossary (cf. Task 2) with a common business vocabulary, i.e., the important and common terms and concepts that frequently and consistently come up when describing the CF Army business and what it does, with a special focus on the TAC organization.
- Develop and document an assessment of the TAC target organization, i.e.,
    - Analyse, assess and document the current status (e.g., the structure, the dynamics, etc.) of the TAC organization in which the situation analysis support system (SASS) is to be eventually deployed.
    - Identify and document the information technology standards for the Army, and any "pre-determined" components of the future information technology architecture.
    - Identify and document current problems in the TAC target organization and areas of potential improvement.
    - Identify and document areas of potential process automation and/or support.
- Identify and document a complete vision of the new target organization for the TAC, written from the stakeholders' perspective, and focusing at the core organization's goals, needs, requirements, essential key features, main constraints, etc.
- Identify and document the business rules, i.e., declarations of policy or conditions that must be satisfied.
- Identify the business actors and use cases and use them to create and document a business use-case model. This shall be a model of the business's intended functions, used as an essential input to identify roles and deliverables in the TAC organization. It shall consist of business actors and business use cases. The actors shall represent roles external to the business (e.g., customers). Business users shall be represented by business actors. Business use cases shall be business processes.
- Identify the business workers, entities, and organizational units, and use them to create and document a business object model. This shall be an object model that describes the realization of business use cases. These realizations shall show how the business use cases are "performed" in terms of interacting business workers and business entities. The roles people play in the TAC organization shall be represented by business workers. The objects that the TAC organization manages or produces shall be represented by business entities. To reflect the various groups or departments in the organization, business workers and business entities shall be grouped into organizational units.

- Identify and document supplementary business specifications, i.e., the contractor shall present the definitions of the TAC business not included in the business use-case model or the business object model.
- Identify and document the high-level requirements of the system needed to support the TAC regarding situation analysis in its target organization.

Software engineering techniques and tools shall be used for this business modeling task. The task shall be an iterative and incremental model development effort; it shall be performed in parallel with other tasks and include verification and validation meetings with SATAC domain SMEs.

The contractor shall document in a report, entitled "Business Model of the Tactical Army Commander Organization", the work performed under this task, along with the corresponding findings and results. The contractor shall also deliver all additional material (which is not necessarily in a "report" format) regarding the business use-case model and the business object model.

<u>Task 6 – Function-Based Goal-Means Decomposition of the SATAC Problem Space</u>

Based on the initial knowledge of SATAC acquired in Task 1 from various documents, and provided along the way with additional knowledge from SMEs (through Task 4), the contractor shall formally capture the essential underlying domain concepts and relationships that define the problem space confronting the SATAC domain practitioners. In particular, the contractor shall develop a structure that links the purposes of individual controllable entities with the overall purpose of work in the SATAC problem space. This shall include knowledge of the domain's characteristics, and the purposes or functions of specific entities within the domain.

The contractor shall make explicit the goals to be achieved in the domain, and the alternative means available for achieving those goals. Actually, the contractor shall model the knowledge acquired through the building of a function-based goal-means decomposition of the problem space, referred to as a Functional Abstraction Network (FAN). This model shall integrate human-centered situation analysis (how tactical army commanders perform situation analysis), computer-centered situation analysis (how software components perform or support situation analysis), and the underlying characteristics of the SATAC work domain.

The contractor shall use the FAN as a recursive goal-means representation, and specify the goals to be reached, the relationships between goals (e.g., goal-sub-goal relations, mutually constraining or conflicting goals), and the means available to achieve the goals (e.g., alternative methods available, pre-conditions, side-effects, preferred order) at ever more increasing levels of abstraction. High-level goals, such as impacting a critical function, shall be decomposed into supporting lower-level sub-goals. The objective shall be to derive, organize, and preserve the goals, processes, critical decisions, and information requirements.

Specific scenario components, in line with the FSO scenario initially provided, shall be generated as part of this task to create test cases to specifically address critical regions of the FAN reflecting critical decisions or specific to previously identified deficiencies of current support systems. These scenario components shall include high-level descriptions of sequences of events and delineate essential/critical aspects relevant to the situation analysis process for the tactical Army commanders.

This task shall be an iterative and incremental model development effort; it shall be performed in parallel with other tasks and include verification and validation meetings with SATAC domain SMEs. While conducting this task, the contractor shall expand the SATAC domain glossary (cf. Task 2) with a common vocabulary, i.e., the important and common terms and concepts that frequently and consistently come up when describing the function-based goal-means decomposition of the SATAC problem space.

The contractor shall document in the report entitled “Cognitive System Engineering Analysis of Situation Analysis for the Tactical Army Commanders” the work performed under this task, along with the corresponding findings and results. The FAN model shall be an appendix to this report. The contractor shall also deliver all additional material (which is not necessarily in a “report” format) regarding the FAN model (e.g., the FAN model shall also be delivered as a number of posters).

<u>Task 7 – Cognitive Analysis of the Work Domain – Cognitive Work Requirements</u>

The contractor shall derive, from a cognitive analysis of the SATAC work domain, the cognitive demands for achieving domain goals, i.e., derive Cognitive Work Requirements (CWRs) for each component of the work domain model (as represented in the FAN developed in Task 6).

The contractor shall transform the domain knowledge insights into appropriate types of situation analysis and problem-solving requirements imposed on the SATAC domain practitioner. Among other things, the CWRs shall document various generic cognitive work types such as goal monitoring, process monitoring, automation supervision, process control, manual takeover, abnormality detection, etc. The CWRs shall be tied directly to elements of goal-process nodes in the FAN to reflect a decision-centered perspective. Actually, the contractor shall overlay the CWRs on the FAN as a way of identifying the cognitive demands/tasks/decisions that arise in the SATAC domain and that require support.

The contractor shall document in the report entitled “Cognitive System Engineering Analysis of Situation Analysis for the Tactical Army Commanders” the work performed under this task, along with the corresponding findings and results. While conducting this task, the contractor shall expand the SATAC domain glossary (cf. Task 2) with a common vocabulary, i.e., the important and common terms and concepts that frequently and consistently come up when describing the CWRs.

<u>Task 8 – Information Relationship Requirements</u>

The contractor shall define, and document in the form of Information Relationship Requirements (IRRs), the information that is needed for each decision to be made, i.e., the information required to perform the cognitive work described by the corresponding CWRs previously identified in Task 7 (or, stated differently, for the successful resolution/execution of each CWR). To achieve this objective, the contractor shall transform relevant insights from knowledge acquisition into information utilized for successful resolution of each CWR in the multi-level model. A single CWR may require multiple IRRs to perform the cognitive work successfully.

The contractor shall identify the information and how it relates to other pieces of information to establish a meaningful context. The focus shall be on identifying the ideal and complete set of information for the associated decision making. That is, the IRRs shall satisfy decision requirements without regard to limitations in data that are available in the current problem-solving environment.

The contractor shall document in the report entitled "Cognitive System Engineering Analysis of Situation Analysis for the Tactical Army Commanders" the work performed under this task, along with the corresponding findings and results. While conducting this task, the contractor shall expand the SATAC domain glossary (cf. Task 2) with a common vocabulary, i.e., the important and common terms and concepts that frequently and consistently come up when describing the IRRs.

Task 9 – Modeling Insights

The contractor shall capture, as modeling insights, the epiphanies that happened while undertaking the analytical process (i.e., while conducting Tasks 4 through 8). The modeling insights shall contain any interesting editorial comments about the particular node of the FAN, provide guidance as to the relative difficulty of CWRs, as well as identify which ones the domain experts find troubling. The contractor shall document as prescriptions for support concepts and/or advanced automation concepts any design ideas that may have occurred during the analysis process.

The contractor shall document in the report entitled "Cognitive System Engineering Analysis of Situation Analysis for the Tactical Army Commanders" the work performed under this task, along with the corresponding findings and results. While conducting this task, the contractor shall expand the SATAC domain glossary (cf. Task 2) with a common vocabulary, i.e., the important and common terms and concepts that frequently and consistently come up when describing the modeling insights.

Task 10 – Validation Sessions with Tactical Army Commanders

The contractor shall conduct validation sessions with subject matter experts from the CF Army, at sites yet to be determined, to confirm that the documented understanding of the "SATAC problem" and the current/future operational requirements, and the functional models resulting form the analysis are consistent with the views of the TAC community. Current tentative dates for these sessions are the 26th week after contract award. This task may require the definition and use of additional, specific scenario components in line with the Full-Spectrum Operations (FSO) scenario initially provided.

The contractor shall document in a report entitled "Validation Sessions with Tactical Army Commanders" the work performed under this task, along with the corresponding findings and results. While conducting this task, the contractor shall expand the SATAC domain glossary (cf. Task 2).

Task 11 – Phase I Final Deliverables and Presentation

In light of the results and findings of the validation sessions (cf. Task 10), the contractor shall make the necessary updates and deliver the final version of all deliverables for Phase I. These deliverables shall serve in Phase II as the basis for the development of visualization and support concepts for SATAC.

The contractor shall also present the results of Phase I to DND/DRDC representatives.

A.4.2 Phase II – Development of Visualization and Support Concepts

In light of the results and findings of Phase I (i.e., the work domain analysis tasks above), the contractor shall develop visualization and support concepts for SATAC through the conduct of some design tasks, taking into account constraints of various types that were intentionally set aside up to this point. The contractor shall apply the main principles of cognitive system engineering that are relevant to this effort while conducting the design activities.

Task 12 – Representation Design Requirements (RDRs) for SATAC

The contractor shall specify the "to-be-designed" support tools by defining the shaping and processing for how the SATAC domain information/relationships should be represented to practitioners. More specifically, the contractor shall transform the CWRs (cf. Task 7) and IRRs (cf. Task 8) into Representation Design Requirements (RDRs) that define the goals and scope of the information representation in terms of the cognitive tasks it is intended to support.

The RDRs shall serve as an explicit documentation of the intent of the presentation, independent of the technologies available, and used to implement the situation analysis support tool. The RDRs shall specify the user's cognitive requirements to be supported and the information transfer objectives to be achieved.

The contractor shall develop the mapping between information on the state and behaviour of the domain (i.e., CWRs and IRRs) and the syntax and dynamics of the visualization or situation analysis aid being developed, i.e., the Presentation Design Concepts (PDCs, cf. Task 13). The contractor shall also produce one traceability/relationship matrix (or design thread matrix) for each functional display, in order to establish the mapping (relationship) between IRRs and RDRs, to explicitly show the RDRs that are intended to satisfy the IRRs.

The contractor shall document in the report entitled "Cognitive System Engineering Design Specification of Situation Analysis Support for the Tactical Army Commanders" the work performed under this task, along with the corresponding findings and results. The traceability/relationship matrices for the functional displays shall be provided as appendices to this report.

While conducting this task, the contractor shall expand the SATAC domain glossary (cf. Task 2) with a common vocabulary, i.e., the important and common terms and concepts that frequently and consistently come up when developing the RDRs.

Task 13 – Presentation Design Concepts (PDCs) for SATAC

The contractor shall design explicit Presentation Design Concepts (PDCs) for the SATAC work domain, to explore techniques to implement the representation requirements into the syntax and dynamics of presentation forms in order to achieve the information transfer to the practitioners.

The contractor shall convert the requirements in each RDR (cf. Task 12) into a sensory presentation form captured as a PDC. The contractor shall follow well accepted best practices for human-computer interfaces/operator-machine interfaces (HCIs/OMIs).

The contractor shall describe the PDCs in enough detail so that an initial system requirement specification (SRS) can be generated for each. As a minimum, the contractor shall describe, for each PDC, its purpose (i.e., its role within the entire situation analysis support system concept and how it works with other PDCs), the RDR coverage, the user interaction associated with the PDC and its dynamic behaviour in response to changes in the world or changes from user interaction, any issues regarding the scope covered by the PDC, and a specification of all scales used within the PDC.

The contractor shall document in the report entitled "Cognitive System Engineering Design Specification of Situation Analysis Support for the Tactical Army Commanders" the work performed under this task, along with the corresponding findings and results. While conducting this task, the contractor shall expand the SATAC domain glossary (cf. Task 2) with a common vocabulary, i.e., the important and common terms and concepts that frequently and consistently come up when developing the PDCs.

Task 14 – Concept-of-Operations (CONOPS) for Situation Analysis Support

The contractor shall develop and document a concept-of-operations (CONOPS) for the proposed situation analysis support for the tactical Army commanders. This CONOPS shall illustrate how the material employed in the support design and the people are expected to work together to conduct situation analysis. It shall provide an indication of how the situation analysis work might be accomplished using the resources found in the design. It shall discuss issues such as data availability, control actions, communications, etc.

The CONOPS shall be developed in parallel with the design tasks previously described (i.e., Tasks 12 and 13).

While conducting this task, the contractor shall expand the SATAC domain glossary (cf. Task 2) with a common vocabulary, i.e., the important and common terms and concepts that frequently and consistently come up when developing the CONOPS.

Task 15 – Animated Visual Situation Analysis Support Storyboard

The contractor shall develop and demonstrate an animated visual situation analysis support storyboard (i.e., a panel or a series of panels making use of an appropriate variety of animated means) that shall be an explicit instantiation of the support needed for the cognitive work requirements (CWRs) previously identified in Task 7. Actually, the storyboard approach shall be used to demonstrate the support system design, the RDRs (cf. Task 12), the PDCs (cf. Task 13), and the CONOPS (cf. Task 14).

Error free and meaningful information shall be used for the situation analysis support displays to avoid distraction in the process of evaluating the value of the situation analysis support concepts.

While conducting this task, the contractor shall expand the SATAC domain glossary (cf. Task 2) with a common vocabulary, i.e., the important and common terms and concepts that frequently and consistently come up when developing the storyboard.

Task 16 – Design Evaluation Methodologies and Review Plan

There is a need to evaluate the design of the situation analysis support concepts proposed for the tactical Army commanders, and resulting from the previous tasks. To fulfill this need, the contractor shall investigate and outline in a report various evaluation methodologies that would be appropriate to obtain insights on the situation analysis support design at a variety of levels, including issues such as the matching of sensory characteristics, adequate usability, providing the required information to the practitioner, supporting the situation analysis demands of the practitioner, supporting the functional space and thus effective situation analysis, supporting the work context, etc.

The contractor shall discuss different evaluation approaches and relate them to the type of problems of interest (i.e., the questions being addressed) and the stage of the design process (i.e., the fidelity of the design artefacts available for the evaluation). The evaluation methodologies considered by the contractor shall not be intended to provide solid scientific experimental proof of the validity of design concepts or of the improvement in the level of situation analysis support. Rather, the methodologies shall be intended to provide more qualitative evidence and appeal to evaluators' intuition and experience in achieving the required level of assurance of the validity of the concepts and of the improvements.

From this investigation of evaluation methodologies, the contractor shall produce and document a plan for the design review activities to be conducted in Task 17. This plan shall include the participation of various Army stakeholders (mainly tactical Army commanders) and of representatives from the cognitive system engineering and scientific communities, and it shall comprise design review sessions for the qualitative assessment of the developed storyboard (cf. Task 15) and the semi-formal evaluation of the proposed situation analysis support design.

In line with the intent stated above, the reviews defined in the plan shall be a “by-inspection” type of evaluation using, for the most part, a mix of static and coarse-grain dynamic presentation of the design concepts. Hence, the reviews shall be reasonably complete in term of the scope of the work domain covered (i.e., features and functionality), but shall be limited in term of dynamic issues.

The contractor shall document in the report entitled “SATAC Support Design Evaluation Methodologies and Review Plan” the work performed under this task, along with the corresponding findings and results.

Task 17 – Design Review Sessions with Tactical Army Commanders

The contractor shall conduct design review sessions, at a site yet to be determined, on the situation analysis support concepts generated by this contract effort, in order to highlight their strengths and weaknesses or design flaws. Current tentative dates for these sessions are the 47th week after contract award.

Through the design review sessions, the contractor shall gain and document both a cognitive system engineering (CSE) point of view and an operational perspective. The design review committee shall thus be composed of representatives from the CSE and situation analysis scientific communities and of experienced tactical Army commanders that will review the adequacy of the proposed design, based upon their operational experience. This task shall thus increase the understanding of the situation analysis support being provided (or that needs to be provided) by vetting the design concepts with groups of experts (i.e., groups mostly composed of experienced practitioners).

The contractor shall follow the design review plan previously elaborated (cf. Task 16). During the review sessions, the contractor shall conduct and document a qualitative assessment of the developed storyboard (cf. Task 14) and a semi-formal evaluation of the proposed situation analysis support design, in order to demonstrate the improvements to the current Army conditions (or the absence of such ameliorations). The reviews shall not be intended to formally validate the adequacy of the situation analysis support that is included in the proposed design. Rather, the results of the reviews shall be intended to identify areas where the design concepts are “on target”, and other areas where additional design effort is needed to address the issues raised during the reviews.

The contractor shall document in the report entitled “SATAC Support Design Review Sessions with Tactical Army Commanders” the work performed under this task, along with the corresponding findings and results. The contractor shall document the design reviews conducted, including the purpose, organization, detailed agenda, benefits, etc. The contractor shall also synthesize the issues that arose in the design reviews into significant design issues that should be addressed in a subsequent analysis/design spiral (likely outside this contract). Hence, the contractor shall provide directions for further work, including an organization and prioritization of the additional design efforts required that were identified through the design review.

Task 18 – Phase II Final Deliverables and Presentation

In light of the results and findings of the design review sessions (cf. Task 17), the contractor shall make the necessary updates and deliver the final version of all deliverables for Phase II.

At this point, these deliverables shall contain a detailed and complete description of the visualization and support concepts for SATAC, and of the activities that were conducted to define them. They shall present the “design thread” and document the transformations from the work domain analysis to the design by presenting the transformations from Information Relationship Requirements (IRRs) to specific situation analysis support concepts described in terms of the associated Presentation Design Concepts (PDCs) and the underlying Representation Design Requirements (RDRs) for each PDC. They shall provide a description of the individual displays of the proposed situation analysis support system in terms of purpose of the display, physical workspace, virtual workspace, interaction needs, salience map, style guide, overall system overview, system navigation, etc. These deliverables shall serve in Phase III as the basis for the specification of the system and software requirements for a situation analysis support system for the tactical Army commanders.

The contractor shall also present the results of Phase II to DND/DRDC representatives.

A.4.3 Phase III – System and Software Requirements

Based on the results and findings of phases I and II, the contractor shall elicit, organize, and document the system and software requirements of the situation analysis support system for the tactical Army commanders in such a way that all stakeholders (including the system developers) understand them. Functional requirements shall be used to express the behaviour of the system, specifying the actions that the system must be able to perform (both the input and output conditions that are expected to result). The non-functional requirements of the system shall also be identified, taking into consideration factors such as usability, reliability, performance, supportability, etc.

Software engineering techniques, more precisely use-case modeling, shall be used for this requirement identification and documentation phase. Use cases are a powerful means of expressing requirements on the functionality of the system. The artefacts developed for this requirements phase shall comprise a system glossary (actually the extension of the glossary initially established in Task 2), a system vision (including a risk list), a system use-case model (including a use-case priority list), and the supplementary system specifications.

Working with the various stakeholders (such as the Scientific Authority and the end users, customers, managers, funding authorities, product champions, etc.), the contractor shall perform the tasks defined next.

<u>Task 19 – Stakeholder Requests and Support System Feature List</u>

Based on the results and findings of phases I and II, the contractor shall explicitly elicit all types of requests from the different stakeholders (customers, users, product champions, etc.), and gather them into a wish list of what they expect or desire the situation analysis support system to include, together with information on how each request has been considered by the project.

The contractor shall also identify and document high-level expressions of the system behaviour as high-level features of the system (the features to be considered for delivery). A feature is a service to be provided by the system that directly fulfills a user need. The contractor shall produce a system feature list for the support system, containing candidate features that could become requirements (i.e., candidate requirements). Good ideas shall be added to the feature list along the way, as the project progresses; the features shall be taken off the list when they become formal requirements.

The contractor shall document in the report entitled “Situation Analysis Support System for the Tactical Army Commander – Stakeholder Requests and System Feature List” the work performed under this task, along with the corresponding findings and results.

<u>Task 20 – Support System Vision and Risk List</u>

Based on the results and findings of phases I and II, the contractor shall develop and document a vision of the situation analysis support system for the tactical Army commanders, containing 1) the set of key stakeholder and user needs, and 2) the high-level features of the system. The contractor shall define the stakeholders’ view of the system to be developed, i.e., provide a complete vision of what needs to be built.

The vision document shall be written from the customers' perspective, focusing on key needs and the essential desired features of the system and acceptable levels of quality. It shall include a problem statement (definition and scope of the problem that one is trying to solve with the system), a description of what will be included, as well as features that were considered but not included. It shall outline the envisioned core requirements, and specify operational capacities (volumes, response times, and accuracies), user profiles, and inter-operational interfaces with entities outside the system boundary, where applicable. Constraints on the development project (e.g., platforms to be supported, etc.) shall also be considered.

Finally, the contractor shall also develop and document a risk list identifying the known and open risks to the project; it shall enumerate hazards that could arise on the way to success.

The contractor shall document in the report entitled "Situation Analysis Support System for the Tactical Army Commander – Vision and Risk List" the work performed under this task, along with the corresponding findings and results. While conducting this task, the contractor shall expand the SATAC domain glossary (cf. Task 2).

Task 21 – Support System Use-Case Model and Priority List

Based on the results and findings of phases I and II, the contractor shall develop a use-case model of the situation analysis support system for the tactical Army commanders. Such a model defines the behaviour of the system from an external perspective. It includes the actors that interact with the system (such as the end user), and the use cases that describe these interactions. Each use case, when detailed, shows step by step how the system interacts with the actors, and what the system does in the use case.

The contractor shall first establish, and document in the system use-case model, the scope of the situation analysis support system, i.e., delimit the system. The contractor shall define and document the boundaries of the system by describing what is to be included in the system (or what will be handled by the system), and what is not (or what will be handled outside the system).

Then, the contractor shall identify the system actors and use cases and document them in the system use-case model. An actor is someone or something outside the system, and that interacts with the system. It can be a person, an external system, or an external device (i.e., who and what will interact with the system). A use case is a description of a complete flow of events (a sequence of actions a system performs) that yields an observable result of value to a particular actor. The use cases and actors shall capture the required system behaviour and interactions. The documentation of each use case shall include a name and a brief description that defines its intent and purpose and outline its content. The name of the use case shall indicate what is achieved through the interactions between the actors and the use case, and shall consist of several words, of which one shall be a verb. The brief description of a use case shall reflect its goal and purpose, shall refer to the actors involved, and shall use the terms defined in the glossary. The most important part of the use case, however, is its flow of events.

The contractor shall model (as associations) the relationships between the actors and use cases to produce a static picture of the communication between the system and its environment. Use-case diagrams and activity diagrams shall be used to visualize the use-case model, including possible relationships among use cases. The contractor shall group the actors and use cases and put them into separate packages in the use-case model.

The contractor shall identify all use-case-specific non-functional requirements, and map them to the appropriate use cases. Examples of non-functional requirements are environmental or implementation constraints, and various qualities: performance, reliability, security, maintainability, extensibility, usability, etc.

The contractor shall prioritize the identified use cases (i.e., define the relative priority of the use cases) and document the results in a system use-case priority list. This list could be used, outside this contract, during iteration planning. The use cases shall be ordered according to established project-specific criteria. These criteria shall, as a minimum, include the benefits to stakeholders, the architectural impact and coverage, and the risks mitigated by addressing the use case. The priorities shall reflect the system vision and the risk list (cf. Task 20). The contractor shall also identify and document which use cases are architecturally significant (i.e., those that represent some significant, central functionality, that have substantial architectural coverage, or that stress or illustrate a specific, delicate point of the architecture).

The contractor shall document in the report entitled "Situation Analysis Support System for the Tactical Army Commander – Use-Case Model and Priority List" the work performed under this task, along with the corresponding findings and results. The contractor shall also deliver all additional material (which is not necessarily in a "report" format) regarding the use-case model. While conducting this task, the contractor shall expand the SATAC domain glossary (cf. Task 2).

<u>Task 22 – Supplementary System Specifications</u>

The contractor shall capture and document in the supplementary system specifications all requirements (e.g., system-wide requirements) that are not associated or applicable to specific use cases (i.e., that are not really captured in the use-case model developed in Task 21). Such requirements shall include legal and regulatory requirements, application standards, quality attributes (such as usability, reliability, scalability, and performance), operating systems and environment requirements, compatibility requirements, and other design and implementation constraints. The supplementary system specifications are an important complement to the use-case model.

The contractor shall document in the report entitled "Situation Analysis Support System for the Tactical Army Commander – Supplementary System Specifications" the work performed under this task, along with the corresponding findings and results. While conducting this task, the contractor shall expand the SATAC domain glossary (cf. Task 2).

<u>Task 23 – Phase III Final Deliverables and Presentation</u>

Based on comments and suggestions received from the Scientific Authority, the contractor shall make the necessary updates and deliver the final version of all deliverables for Phase III.

The contractor shall also present the results of Phase III to DND/DRDC representatives.

A.5 Reports / Deliverables

The following table lists the reports/deliverables of this contract, and provides a high-level schedule for these elements.

Table 5: Reports/deliverables of the example contract and high-level schedule

Reports/Deliverables	Schedule
Task 1 Report: Initial Assessment of Situation Analysis for the Tactical Army Commanders	4 weeks after contract award.
Task 2 Report: Glossary on Situation Analysis for the Tactical Army Commander	4 weeks after contract award for the initial version. The glossary shall be continually refined throughout the contract execution, and interim versions shall be provided to the Scientific Authority, on demand. A "final" version shall be delivered at the end of each of the three phases of the contract.
Task 3 Report: Tactical Army Commander Knowledge Acquisition Plan	4 weeks after contract award.
Task 4 Report: Situation Analysis Knowledge Acquisition from Tactical Army Commanders	10 weeks after contract award for the initial version. 15 weeks after contract award for the final version.
Task 5 Report: Business Model of the Tactical Army Commander Organization	10 weeks after contract award for the initial version: "Interim Version #1". 15 weeks after contract award for an updated version: "Interim Version #2". 30 weeks after contract award for the final version.
Tactical Army Commander Organization – Business Use-Case Model	10 weeks after contract award for the initial version: "Interim Version #1". 15 weeks after contract award for an updated version: "Interim Version #2". 30 weeks after contract award for the final version.
Tactical Army Commander Organization – Business Object Model	10 weeks after contract award for the initial version, i.e., "Interim Version #1". 15 weeks after contract award for an updated version: "Interim Version #2".

Reports/Deliverables	Schedule
	30 weeks after contract award for the final version.
Tasks 6-9 Report: Cognitive System Engineering Analysis of Situation Analysis for the Tactical Army Commanders	10 weeks after contract award for the initial version: “Interim Version #1”, documenting initial results on the function-based goal-means decomposition of the SATAC problem space, including the Functional Abstraction Network (FAN). 15 weeks after contract award for an updated version, i.e., “Interim Version #2”, providing updates on previous material, and documenting initial results on the Cognitive Work Requirements (CWRs). 20 weeks after contract award for an updated version, i.e., “Interim Version #3”, providing updates on previous material, and documenting initial results on the Information Relationship Requirements (IRRs). 24 weeks after contract award for an updated version, i.e., “Interim Version #4”, providing updates on previous material, and documenting the modeling insights. 30 weeks after contract award for the final version.
Situation Analysis for the Tactical Army Commanders – Functional Abstraction Network (FAN)	10 weeks after contract award for the initial version: “Interim Version #1”. 15 weeks after contract award for an updated version, i.e., “Interim Version #2”. 20 weeks after contract award for an updated version, i.e., “Interim Version #3”. 24 weeks after contract award for an updated version, i.e., “Interim Version #4”. 30 weeks after contract award for the final version.
Test Cases Scenarios Report	6 weeks after contract award for the initial version: “Interim Version #1”. 11 weeks after contract award for an updated version, i.e., “Interim Version #2”. 24 weeks after contract award for the “Phase I Final Version”. 45 weeks after contract award for the “Phase

Reports/Deliverables	Schedule
	II Final Version".
Task 10 Report: Validation Sessions With Tactical Army Commanders	29 weeks after contract award.
Phase I Final Deliverables and Presentation	30 weeks after contract award.
Tasks 12-13 Report: Cognitive System Engineering Design Specification of Situation Analysis Support for the Tactical Army Commanders	35 weeks after contract award for the initial version: "Interim Version #1", documenting initial results on the Representation Design Requirements (RDRs) for SATAC. 38 weeks after contract award for an updated version, i.e., "Interim Version #2", providing updates on previous material, and documenting initial results on the Presentation Design Concepts (PDCs) for SATAC. 41 weeks after contract award for an updated version, i.e., "Interim Version #3". 51 weeks after contract award for the final version.
SATAC: Traceability/ Relationship Matrices for Functional Displays (An Appendix to the Tasks 12-13 Report)	35 weeks after contract award for the initial version: "Interim Version #1". 38 weeks after contract award for an updated version, i.e., "Interim Version #2". 41 weeks after contract award for an updated version, i.e., "Interim Version #3". 51 weeks after contract award for the final version.
Concept-of-Operations (CONOPS) for Next-Generation Computer-Based Support Systems for SATAC	38 weeks after contract award for the initial version: "Interim Version #1". 41 weeks after contract award for an updated version, i.e., "Interim Version #2". 51 weeks after contract award for the final version.
Animated Visual Situation Analysis Support Storyboard	41 weeks after contract award for the initial version: "Interim Version #1". 45 weeks after contract award for an updated version, i.e., "Interim Version #2".

Reports/Deliverables	Schedule
	51 weeks after contract award for the final version.
Task 16 Report: SATAC Support Design Evaluation Methodologies and Review Plan	45 weeks after contract award.
Task 17 Report: SATAC Support Design Review Sessions With Tactical Army Commanders	51 weeks after contract award.
Phase II Final Deliverables and Presentation	52 weeks after contract award.
Task 19 Report: Situation Analysis Support System for the Tactical Army Commander – Stakeholder Requests and System Feature List	54 weeks after contract award.
Task 20 Report: Situation Analysis Support System for the Tactical Army Commander – Vision and Risk List	56 weeks after contract award.
Task 21 Report: Situation Analysis Support System for the Tactical Army Commander – Use-Case Model and Priority List	56 weeks after contract award for the initial version: “Interim Version #1”. 59 weeks after contract award for an updated version, i.e., “Interim Version #2”. 62 weeks after contract award for the final version.
Use-Case Model	56 weeks after contract award for the initial version: “Interim Version #1”. 59 weeks after contract award for an updated version, i.e., “Interim Version #2”. 62 weeks after contract award for the final version.
Task 22 Report: Situation Analysis Support System for the Tactical Army Commander – Supplementary System Specifications	56 weeks after contract award for the initial version: “Interim Version #1”. 59 weeks after contract award for an updated version, i.e., “Interim Version #2”. 62 weeks after contract award for the final version.
Phase III Final Deliverables and Presentation	62 weeks after contract award for the final version.

A.6 Master Schedule

Figures 18 and 19 provide a representative master schedule for the various tasks described above for the contract example. In this example, the contract has a duration of 62 weeks; this represents a very aggressive schedule.

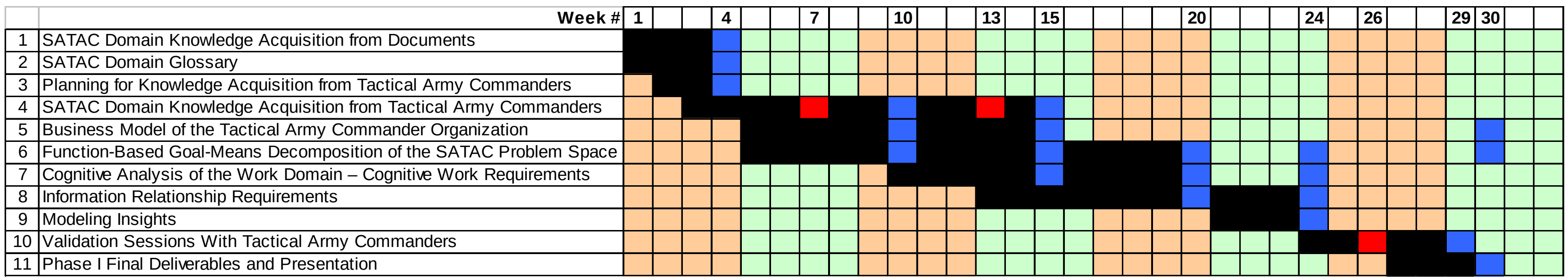

Figure 18: Schedule example for Phase I – Work Domain Analysis

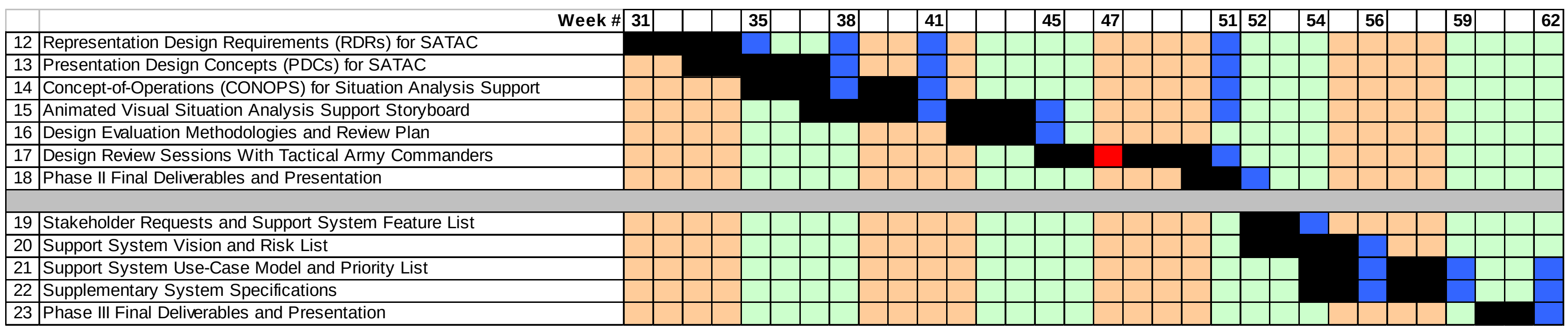

Figure 19: Schedule example for Phase II – Development of Visualization and Support Concepts and Phase III – System and Software Requirements

List of symbols/abbreviations/acronyms/initialisms

ACWA	Applied Cognitive Work Analysis
AI	Artificial Intelligence
AKAMIA	Advanced Knowledge Acquisition for Maritime Information Awareness
ARP	Applied Research Program
ASCAT	Analyse de la situation pour le commandant d'armée tactique
ASFI	Analyse de la situation et fusion d'information
BB	Blackboard
C2	Command and Control
C4I	Command and Control, Communications, Computers and Intelligence
CASE ATTI	Concept Analysis and Simulation Environment for Automatic Target Tracking and Identification
CCIS	Command and Control Information System
CCRP	Command and Control Research Program
CF	Canadian Forces
CKE-4-MDA	Collaborative Knowledge Exploitation for Maritime Domain Awareness
CODSI	Command Decision Support Interface
CONOPS	Concept of Operations
CSE	Cognitive System Engineering
CTA	Cognitive Task Analysis
CWA	Cognitive Work Analysis
CWR	Cognitive Work Requirement
DB	Database
DM	Decision Making
DND	Department of National Defence
DoD	Department of Defense
DRDC	Defence R&D Canada
DSS	Decision Support System
ECCESDM	Exploitation collaborative de la connaissance pour l'éveil situationnel du domaine maritime
ED	Expert du domaine
ES	Expert System
FAN	Functional Abstraction Network

FSO	Full-Spectrum Operations
GFI	Government Furnished Information
HCI	Human-Computer Interface
IEC	International Electrotechnical Commission
IKM	Information and Knowledge Management
INCOMMANDS	Innovative Naval Combat Management Decision Support
IRR	Information/Relationship Requirement
ISO	International Organization for Standardization
JCDS 21	Joint Command Decision Support for the 21st Century
JDL DIFG	Joint Directors of Laboratories' Data and Information Fusion Group
JIIFC	Joint Information and Intelligence Fusion Capability
KB	Knowledge Base
KID	Knowledge, Information, Data
KNOWMES	Knowledge Management and Exploitation Server
LF ISTAR	Land Force Intelligence, Surveillance, Target Acquisition and Reconnaissance
LOE	Limited Objective Experiment
MDN	Ministère de la Défense nationale
M&S	Modeling and Simulation
MSDF	Multi-Sensor Data Fusion
MSOC	Marine Security Operations Centres
MSP	Multiple-Source Processing
OMI	Operator-Machine Interface
PADB	Performance Analysis Database
PDC	Presentation Design Concept
PE	Performance Evaluation
PRA	Programme de recherches appliquées
R&D	Research & Development
RDR	Representation Design Requirement
RUP	Rational Unified Process
SA	Situation Analysis
SAIF	Situation Analysis and Information Fusion
SARAD	System Architecture and Requirements Allocation Description
SASS	Situation Analysis Support Systems

SATAC	Situation Analysis for the Tactical Army Commander
SAW	Situation Awareness
SE	Situation Element
SE	Software Engineering
SEATS	Simulation Environment for the Analysis of the Tactical Situation
SME	Subject Matter Expert
SOA	Service-Oriented Architecture
SOW	Statement of Work
SRD	Software Requirements Description
SRS	System Requirements Specification
SSAS	Système de soutien à l'analyse de la situation
SSP	Single-Source Processing
S&T	Science and Technology
TAC	Tactical Army Commander
TCT	Time Critical Target
TDP	Technology Demonstration Program
TR	Technical Report
U.S.	United States
VIP	Very Important Person

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Situation awareness has emerged as an important concept around dynamic human decision-making in both military and public security environments, and situation analysis is defined as the process that provides and maintains a state of situation awareness for the decision makers. Information fusion is a key enabler to meeting the demanding requirements of situation analysis in future command and control and intelligence support systems. Combining elements of information fusion and knowledge-based systems, this report presents a holistic approach and framework, including some recommended high-level steps, for the overall development and evaluation of any knowledge-based situation analysis support system. The report provides a fair description of the approach, thereby contributing to the set up of a foundational R&D framework for two projects that are just starting at Defence R&D Canada. Emphasis is given to the knowledge-centric aspects of the approach. Topics being discussed include cognitive, software, knowledge and ontological engineering. Subject matter experts, situation analysis processing nodes and processing trees, a priori supporting knowledge, system architecture issues, evaluation in laboratory testbeds using modeling and simulation, field demonstrations and experiments, and expert system development are other aspects being discussed in the report.

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