Comparative Study of Formal Knowledge Representation Enablers for the Collaborative Knowledge Exploitation Framework

Final Report

July 13, 2007

DRDC Valcartier CR 2007-175

Gary Reedel

MacDonald Dettwiler and Associates Ltd.

PWGSC Contract Title	Collaborative Knowledge Exploitation Framework
MDA Project Title:	5272 – CKEF
MDA Document Number:	CKEF-RP-52-5274
Contract No.:	W7701 – 062549/001/QCL
Project Duration:	January 2007 – June 2008
DRDC Project Manager:	M. Jean Roy, (418) 844-4000 ext. 4379
DRDC Scientific Authority:	M. Jean Roy, (418) 844-4000 ext. 4379
DRDC Document Number:	CR 2007-175

© Copyright Her Majesty the Queen in Right of Canada (2007)

13800 Commerce Parkway
Richmond, B.C., Canada, V6V 2J3
Telephone (604) 278-3411
Fax (604) 231-2753

RESTRICTION ON USE, PUBLICATION, OR DISCLOSURE OF PROPRIETARY INFORMATION

This document contains information proprietary to Her Majesty the Queen in Right of Canada, to MacDonald Dettwiler and Associates Ltd., or to a third party to which Her Majesty the Queen in Right of Canada or MacDonald Dettwiler and Associates Ltd. may have a legal obligation to protect such information from unauthorized disclosure, use or duplication. Any disclosure, use or duplication of this document or of any of the information contained herein for other than the specific purpose for which it was disclosed is expressly prohibited, except as Her Majesty the Queen in Right of Canada or MacDonald Dettwiler and Associates Ltd. may otherwise agree to in writing.

The scientific or technical validity of this Contract Report is entirely the responsibility of the contractor and the contents do not necessarily have the approval or endorsement of Defence R&D Canada.

THIS PAGE INTENTIONALLY LEFT BLANK

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

Comparative Study of Formal Knowledge Representation Enablers for the Collaborative Knowledge Exploitation Framework

Final Report

July 13, 2007

DRDC Valcartier CR 2007-175

Gary Reedel

MacDonald Dettwiler and Associates Ltd.
13800 Commerce Parkway
Richmond, BC, Canada
V6V 2J3

PWGSC Contract Title	Collaborative Knowledge Exploitation Framework
MDA Project Title:	5272 – CKEF
MDA Document Number:	CKEF-RP-52-5274
Contract No.:	W7701 – 062549/001/QCL
Project Duration:	January 2007 – June 2008
DRDC Project Manager:	M. Jean Roy, (418) 844-4000 ext. 4379
DRDC Scientific Authority:	M. Jean Roy, (418) 844-4000 ext. 4379
DRDC Document Number:	CR 2007-175

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

Prepared By:	G. Reedel	Signature and Date
Deputy Project Manager:	C. Nadeau	
Project Manager:	H. Zwick	

MacDonald Dettwiler and Associates Ltd
13800 Commerce Parkway
Richmond, BC, Canada
V6V 2J3

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

CHANGE RECORD

ISSUE	DATE	PAGE(S)	DESCRIPTION	RELEASE
1/0	Mar. 30, 2007	All	First Issue - Draft	
1/1	June 12, 2007	All	First Issue - First Revision	
1/2	July 13, 2007	All	First Issue - Second Revision	

Use, duplication, or disclosure of this document or any of the information
contained herein is subject to the restrictions on the title page of this document.

THIS PAGE INTENTIONALLY LEFT BLANK

Use, duplication, or disclosure of this document or any of the information
contained herein is subject to the restrictions on the title page of this document.

TABLE OF CONTENTS

1 INTRODUCTION 1-1
1.1 Project and Contract Background 1-2
1.1.1 National Requirements for Information Superiority 1-2
1.1.2 Maritime Domain Awareness 1-3
1.1.3 National Command Structure 1-4
1.1.4 Knowledge Management and Exploitation Terminology 1-7
1.2 The CKEF Contract 1-10
1.2.1 Technical Vision for the CKE-4-MDA Project 1-10
1.2.2 CKEF Contract 1-11
1.2.3 The Collaborative Knowledge Exploitation Framework 1-15
1.2.4 The Knowledge Mapping Application 1-16
1.3 The Contract Team 1-16

2 KR ENABLER REQUIREMENTS ANALYSIS 2-1
2.1 Requirements for Knowledge Representation 2-2
2.2 Background 2-3
2.2.1 Semantic Ontology Spectrum 2-3
2.2.2 Resource Description Framework (RDF) 2-4
2.2.3 Web Ontology Language (OWL) 2-5
2.2.4 Non Monotonic Reasoning 2-5
2.2.5 Truth Maintenance Systems 2-7
2.3 Related Work 2-7
2.3.1 Ontology-based Rules 2-7
2.3.2 Supporting What, Where and When Queries? 2-8
2.3.3 Query languages for the Semantic Web 2-9
2.3.4 Personal Information Management 2-10
2.3.5 Truth Maintenance 2-11

3 ENABLER TECHNOLOGY REVIEW 3-1
3.1 Approach 3-1
3.1.1 Review Criteria 3-1
3.2 Knowledge Representation Creation 3-2
3.2.1 Applicable OWL Ontologies 3-4
3.3 Knowledge Representation Storage and Querying Tools 3-5
3.4 Knowledge Representation Visualization 3-7
3.5 Knowledge Representation Inferring 3-9
3.6 Rule engines 3-10
3.7 Knowledge Representation Querying 3-12

Use, duplication, or disclosure of this document or any of the information
contained herein is subject to the restrictions on the title page of this document.

3.8 Weak Semantic Methods 3-12
3.9 Workflow / Process Knowledge 3-15
3.9.1 Technology Evaluation 3-15
3.9.2 Tool Evaluation 3-17
3.10 Human Expertise Network 3-20

4 RECOMMENDATIONS 4-1

5 DOCUMENTS 5-1
5.1 Applicable Documents 5-1
5.2 Reference Documents 5-1

Use, duplication, or disclosure of this document or any of the information
contained herein is subject to the restrictions on the title page of this document.

LIST OF FIGURES

Figure 1-1 Reporting Structures for Maritime Domain Awareness 1-6
Figure 1-2 Knowledge Management and Exploitation Topics 1-9
Figure 1-3 Data Flow Diagram and the Interdependence between Activities 1-12
Figure 1-4 Scope of CKEF in CKE-4-MDA 1-15
Figure 2-1 Semantic Ontology Spectrum (Ref R-18) 2-4

Use, duplication, or disclosure of this document or any of the information
contained herein is subject to the restrictions on the title page of this document.

THIS PAGE INTENTIONALLY LEFT BLANK

Use, duplication, or disclosure of this document or any of the information
contained herein is subject to the restrictions on the title page of this document.

LIST OF TABLES

Table 3-1 Protégé Specifications 3-2
Table 3-2 SWOOP Specifications 3-3
Table 3-3 TopBraid Composer™ Specifications 3-3
Table 3-4 SemanticWorks Specifications 3-4
Table 3-5 Sesame Specifications 3-5
Table 3-6 SWOOP Visualization Specifications 3-7
Table 3-7 Protégé Jambalaya Visualization Specifications 3-7
Table 3-8 Protégé PROMPTViz Visualization Specifications 3-8
Table 3-9 IsaViz Visualization Specifications 3-8
Table 3-10 Jena2 Specifications 3-9
Table 3-11 Pellet Specifications 3-9
Table 3-12 RACER Specifications 3-10
Table 3-13 Weak Semantic Enablers. 3-12
Table 3-14 WordNet Specifications 3-14
Table 3-15 jPDL Specifications 3-15
Table 3-16 BPEL Specifications 3-16
Table 3-17 BPEL4People Specifications 3-16
Table 3-18 XPDL Specifications 3-17
Table 3-19 JBoss jBPM Specifications 3-17
Table 3-20 Apache ODE Specifications 3-18
Table 3-21 Oracle Business Process Manager Specifications 3-18
Table 3-22 Enhydra Shark Workflow Specifications 3-19
Table 3-23 Adobe Livecycle Workflow Specifications 3-19
Table 3-24 FOAF Specifications 3-21
Table 3-25 XFN Specifications 3-21

Use, duplication, or disclosure of this document or any of the information
contained herein is subject to the restrictions on the title page of this document.

THIS PAGE INTENTIONALLY LEFT BLANK

Use, duplication, or disclosure of this document or any of the information
contained herein is subject to the restrictions on the title page of this document.

ACRONYMS AND ABBREVIATIONS

API	Application Programming Interface
BPEL	Business Process Execution Language 4 People
Canada COM	Canada Command
CANSOCOM	Canadian Operational Support Command
CANSOFCOM	Canadian Special Operations Forces Command
CDS	Chief of Defence Staff
CEFCOM	Canadian Expeditionary Forces Command
CKEF	Collaborative Knowledge Exploitation Framework
CV	Command View
DRDC	Defence Research and Development Canada
FOAF	Friend Of A Friend
FOIE	Force Opérationnelle Interarmées Est
IMSWG	Interdependent Marine Security Working Group
jBPM	Java Business Process Management
JCC	Joint Command Centre
JIOC	Joint Interagency Operations Centre [now RJOC (A)]
JOC	Joint Operations Centre [now RJOC (P)]
jPDL	Java Process Description Language
JTF	Joint Task Force
JTFA	Joint Task Force Atlantic
JTFAFG	Joint Task Force Afghanistan
JTFC	Joint Task Force Central
JTFE	Joint Task Force East
JTFG	Joint Task Force Games
JTFN	Joint Task Force North

Use, duplication, or disclosure of this document or any of the information
contained herein is subject to the restrictions on the title page of this document.

JTFP	Joint Task Force Pacific
JTFW	Joint Task Force West
KA	Knowledge Asset
KAI	Knowledge Assets Inventory
KME	Knowledge Management and Exploitation
KR	Knowledge Representation
MDA	Maritime Domain Awareness
OGD	Other Government Departments
OWL	Web Ontology Language
PIM	Personal Information Management
RDF	Resource Description Framework
RDMS	Relational Database Management System
RJOC(A)	Regional Joint Operations Centre (Atlantic)
RJOC(P)	Regional Joint Operations Centre (Pacific)
RJTF	Regional Joint Task Force
SAIL	Storage And Inference Layer
SOP	Standard Operating Procedure
SWRL	Semantic Web Rule Language
TMS	Truth Maintenance System
TTCP	The Technical Communication Panel
URL	Uniform Resource Identifiers
XHTML	XFT Friend Network
XML	eXtensible Markup Language
XPDL	XML Process Definition Language
WMC	Workflow Management Coalition

Use, duplication, or disclosure of this document or any of the information
contained herein is subject to the restrictions on the title page of this document.

1 INTRODUCTION

This is a report describing a comparative study of formal knowledge representation enablers for the knowledge exploitation framework.. The work was done under Defence Research and Development Canada (DRDC) Valcartier contract W7701-062549/001/QCL [A-1], titled "Development of a Collaborative Knowledge Exploitation Framework (CKEF) for the Maritime Domain Awareness Operations Centres and of a K-mapping Application." The work described here is a deliverable under Activity 1.3 according to the Statement of Work discussed in Section 1.1.3.

The following subsections provide background information common to all activities within this contract. They are based on the introductory text for the Statement of Work in the contract document [ref A-1]. Some terminology has been changed to reflect changes in the CF operations and amplifying material has been inserted to clarify how we use some of the technical terms in this contract.

Section 1.1 introduces key concepts, terminology, and acronyms to be used throughout this report. Section 1.2 describes the objectives of the parent "CKE-4-MDA" project and of this specific contract. Section 1.3 introduces the contract team.

Section 2.1 introduces requirements for the knowledge representation. Section 2.2 provides some background descriptions of technology. Section 2.3 describes several research programs applicable to the CKEF. Section 3 documents a review of technology enablers for knowledge representations and documents selected enablers products against a standard set of criteria. Section 4 provides recommendations for the best candidate enabler technologies for the CKEF.

Project and Contract Background

The SOW defines the following names for this contract and its parent project:

- **CKE-4-MDA Project:** DRDC's "Collaborative Knowledge Exploitation for Maritime Domain Awareness" project. The overall objective of the

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

CKE-4-MDA project is to develop an integrated collaborative knowledge exploitation framework (i.e. a set of computer and software tools) that will improve maritime domain awareness by helping staff at the regional joint operations centres and Canada Command (Canada COM) to "quickly find, access, create, organize, share, use, and reuse relevant knowledge" [A-1 pg 19].

- **CKEF Contract**: the current contract led by MacDonald Dettwiler and Associates, Ltd. [A-1], titled "Development of a CKEF for the Maritime Domain Awareness Operations Centres and of a K-mapping Application." The CKEF Contract is funded under the CKE-4-MDA Project.
- **Activity**: when referenced to this CKEF Contract, this means one of the itemized activities listed in the Statement of Work, and numbered from 1.1 to 2.6 [A-1 pages 21 through 24]

The following subsections clarify the following terms used in the above list:

- Sections 1.1.1 and 1.1.2 review the need for domain awareness in Canada, and the definition of "maritime domain awareness" used by this contract
- Section 1.1.3 introduces the names that will be used for the regional joint operations centres and Canada COM
- Section 1.1.4 defines knowledge management terms such as "knowledge exploitation" and "k-Mapping"
- Section 1.2 summarizes the CKEF contract, including the engineering vision for the CKEF and K-Mapper
- Section 1.3 introduces the contract team

1.1 Project and Contract Background

1.1.1 National Requirements for Information Superiority

Canada's National Security Policy recognizes the need for better intelligence, and explicitly links it to the Canadian government's ability to plan for, allocate resources to, and respond to crises:

> To manage risk effectively, we need the best possible information about threats we face and about the intentions, capabilities and activities of those who would do us harm. The best decisions regarding the scope and design of security programs and the allocation of resources and the deployment of assets cannot be made unless decision makers are as informed as possible…[ref R-1, pg 15]

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

The 2005 Defence Policy Statement affirms the need for fast information management:

> The rapid acquisition and sharing of information will be critical to future operations. Commanders and subordinates at every level need to know what is happening before they can respond to incidents. [ref R-2 pg 12]

DRDC, in its *Technology Investment Strategy* summarizes the importance of information and knowledge superiority as follows:

> The doctrine of information and knowledge superiority has become the basis for structuring C2 architectures and operations. Battlespace superiority and operational effectiveness are threatened by poor information. The organization must learn from experience and apply that knowledge judiciously to fulfill its mission. [ref R-3 pg 12]

It proposes three information and knowledge management tasks, the second of which is:

> **Knowledge modelling, discovery and creation for improved situational awareness:** Investigate and advance knowledge creation and discovery techniques through which we collect and process information to gain sufficient situational awareness to be able to project possible future courses of action or trends with confidence. [ref R-3 pg 12]

1.1.2 Maritime Domain Awareness

DRDC offers the following definition of "Maritime Domain Awareness," based on minutes from The Technical Communication Panel (TTCP) [ref R-4] and a definition from the Interdepartmental Marine Security Working Group (IMSWG) [ref R-5]

> Maritime Domain Awareness (MDA) has to do with the effective understanding of any activity associated with the maritime environment that could impact security, safety, economy or environment. MDA comprises the contextualization of positional and identification data with intelligence data. A NATO definition states that MDA is about all areas and things of, on, under, relating to, adjacent to, or bordering on a sea, ocean, or other navigable waterway; including all maritime related activities, infrastructure, people, cargo and vessels and other conveyances. In Canada, the MDA activity sphere includes Canada's surveillance and awareness efforts within marine zones as well as liaison and coordination with Canadian and international intelligence gathering bodies. Within this activity sphere, security efforts are guided by the principle that the greater the vulnerability, the more detailed the Government of Canada's information requirements. Key objectives include developing comprehensive knowledge of people, containers, goods and vessels from foreign points of origin to Canadian points of destination; and timely information collection and sharing among key departments through secure means. Collaboration is key to the effectiveness of domain awareness, responsiveness and safeguarding activities. [A-1 pg 17-18]

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

1.1.3 National Command Structure

The Defence Policy Statement of 2005 [ref R-2] initiated a major reorganization of Canadian Forces to enhance their ability to deploy, at home and abroad, and to respond to terrorist threats. Under the new organization, four operational commands report to the Chief of Defence Staff (CDS):

- Canada Command ("Canada COM")
- Canadian Expeditionary Forces Command ("CEFCOM")
- Canadian Special Operations Forces Command ("CANSOFCOM")
- Canadian Operational Support Command ("CANOSCOM")

Canada COM is the operational command assigned to the defence of Canada and assistance to Other Government Departments (OGD) and provinces in domestic operations. Canada COM's very wide mandate for continental defence is summarized as follows:

> Canada COM is a single, joint, unified and integrated command responsible for all domestic routine and contingency operations. It views the country as a single operational area with the national headquarters exercising command and control via six asymmetric, subordinate commands, which reflect the regional nature of the country. The Commander Canada COM is responsible for the conduct of all domestic operations and is the national operational authority for the defence of Canada and North America. [ref R-7 pg iii].

The operational commands rely heavily on the concept of a "Joint Task Force" (JTF), which is a "fully integrated unit capable of a timely, focused and effective response to foreign or domestic threats to Canadian security…" and safety of our population [ref R-1 pg 11]. Examples of JTFs with special focus are: Joint Task Force Afghanistan (JTF AFG), Joint Task Force Games (JTFG), and Joint Task Force 2 (JTF 2).

There are six permanent Regional Joint Task Forces (RJTFs):

- **Joint Task Force Pacific** (**JTFP**): responsible for British Columbia and Canada's Pacific area of responsibility;
- **Joint Task Force Atlantic** (**JTFA**): responsible for the Atlantic provinces, Labrador, and Canada's Atlantic area of responsibility (which includes the waterways of the Eastern Arctic);
- Joint Task Force West (JTFW): Alberta, Saskatchewan, and Manitoba
- Joint Task Force Central (JTFC): Ontario and the Great Lakes;

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

- Joint Task Force East (JTFE), also known as Force Opérationnelle Interarmées Est (FOIE): Quebec and the St. Lawrence Seaway;
- Joint Task Force North (JTFN): Yukon, Northwest Territories, and Iqualuit

Responsibility for building and maintaining maritime domain awareness flows down from Canada COM to JTFA and JTFP, as shown in Figure 1-1. Canada COM, JTFA, and JTFP then achieve MDA through their command and operations centres, which are referred to, in this document, as follows:

- **Joint Command Centre** (**JCC**): located in Ottawa, JCC serves as the "focal point for interaction with the JTFs, other military operations centres, and the Government of Canada" [ref R-7 pg 9-1/4]. It operates 24/7 and is supervised by Canada COM J3.
- **Regional Joint Operations Centre Atlantic** (**RJOC(A)**): located at the naval base in Halifax, RJOC(A) operates 24/7 at JTFA and takes primary responsibility for maritime domain awareness in the Atlantic and Eastern Arctic. RJOC(A) used to be the Joint Interagency Operations Centre (JIOC).
- **Regional Joint Operations Centre Pacific** (**RJOC(P)**): located at the naval base in Esquimalt, RJOC(P) operates 24/7 under the supervision of JTFP J3 and takes primary responsibility for maritime domain awareness in the Pacific and Western Arctic. RJOC(P) has been a component of Operational Support Centre Pacific (OSCP) also known as ATHENA, but JTFP has announced that ATHENA will cease to exist because its activity will be absorbed into JTFP [ref R-8, pg B 2/2]. RJOC(P) was formerly known as the "Joint Operations Centre" (JOC).

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

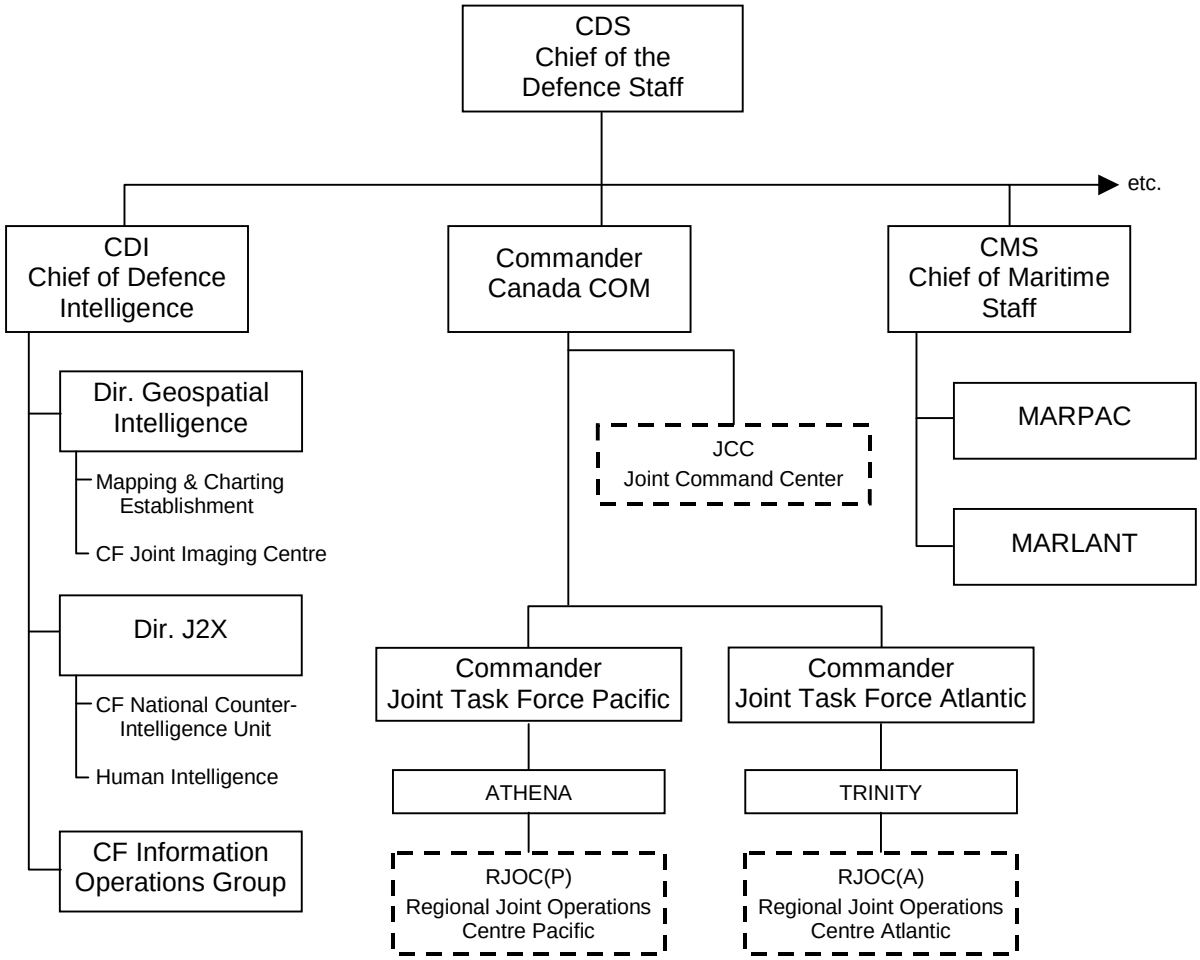

Figure 1-1 Reporting Structures for Maritime Domain Awareness

MDA is primarily the responsibility of the Regional Joint Operations Centers RJOC(A) and RJOC(P), which are part of JTFA and JTFP, reporting to Canada Command. Maritime assets such as ships are currently commanded through MARLANT and MARPAC, but there are preliminary plans to shift this to a "Maritime Component Commander" under JTFA and JTFP. MDA relies on intelligence information from non-CF agencies not shown here, and occasionally from the defence intelligence agencies shown on the left. [ref R-8 pg B-2-7/18, ref R-16, and ref R-7 pg 4-3/8]

Use, duplication, or disclosure of this document or any of the information
contained herein is subject to the restrictions on the title page of this document.

1.1.4 Knowledge Management and Exploitation Terminology

This section clarifies what is meant by the various "knowledge" terms in the CKEF Contract [A-1 pp 17-19] for the purposes of this contract. The terms, and their meanings are:

- **Knowledge:** a combination of information and understanding on a subject [ref R-9 pg 85, ref R-10]. As with many authors [e.g. ref R-3 pg 11], we make no clear distinction between *knowledge* and *information* in the context of maritime domain awareness.
- **Knowledge Atom:** one single piece of knowledge, such as "there are no ships in this region." Knowledge atoms typically contain knowledge about situation elements.
- **Knowledge Broker:** a system or a person that will find and deliver knowledge atoms upon demand, or disseminate knowledge atoms to interested parties.
- **Knowledge Asset (KA):** a person or a system able to deliver knowledge atoms, or to which newly created knowledge atoms are routinely delivered. A knowledge asset may be the *source* of knowledge (e.g. the person who first identified the ship), a *repository* for the knowledge (e.g. a log book in which the ship's identity was recorded), or a *knowledge broker* (e.g. the Intelligence Officer of the Watch, who knows whom to ask to find out whether the ship has been identified).
- **Knowledge Artefact:** an object that contains explicit knowledge on a support made by either human or machine. These artefacts can take different shapes or forms like a web site, a database, a document, etc. They are thus a special sub-class of knowledge asset: any knowledge asset that is not a person.
- **Knowledge Assets Inventory (KAI):** a list in which each record describes a KA in terms of a large set of attributes.
- **Knowledge Management and Exploitation (KME):** activities such as the following (as shown in Figure 1-2, that can be applied to a knowledge): acquire, extract, retrieve, capture, solicit, collect, access, gather, represent, encode, index, classify, store, map, cleanse, tag, structure, collate, fuse, combine, filter, integrate, link, transform, reason, infer, extrapolate, process, evaluate, assess, analyse, exploit, use, reuse, create, generate, learn, present, visualise, display, exchange, share, advertise, subscribe, transfer, deliver, restrict access to, disseminate, publish, search, find, reveal, mine, discover. [ref R-11 pg 13]
- **Formal Representation Enabler:** a means of expressing and encoding knowledge so that they can be read and understood by computers. This will generally include a format or language for storing knowledge, plus an analytical process by which knowledge is encoded and decoded.

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

- **Knowledge Map:** "A visual presentation of knowledge assets within an organisation as well as their relationships with one another and their dependencies" [ref R-11 pg. 31]. Where possible, it includes links to the knowledge assets and instructions for extracting knowledge atoms but it does not contain knowledge atoms.
- **K-Mapper:** a tool for displaying and exploring RJOC(A)/RJOC(P)/JCC-specific knowledge maps. This is the project name for software that meets the requirement for a "K-mapping Application" [A-1 pp 17, 22, 24 of 31], a "knowledge mapping (k-mapping) application" [A-1 pp 17, 19, 24 of 31], and a "knowledge mapping application" [A-1 pp 19, 23, 25 of 31].
- **Situation:** A specific combination of circumstances, i.e. conditions, facts, or states of affairs, at a certain moment. A situation is a combination of situation elements.
- **Situation Element:** A constituent part of a situation. Examples of generic situation elements are entities, identity, kinematics, sensors, weapons, capabilities, intentions, behaviours, actions, impacts, threats, terrain, etc. Examples of specific situation elements in the maritime domain are vessel, cargo, container, crew, owner, port, health inspection, shipping routes, coastal infrastructure, beach, weather, ice conditions, piracy, illegal fishing, marine life protection, pollution violations, etc.
- **Situational Awareness:** "the dynamic understanding of the environment surrounding a theatre of operations." [ref R-7 pp 1A 12/12]. Canada Command understands that Situational Awareness includes [ref R-7 pp 1A 12/12]:
    - the critical factors that affect the physical environment (weather, geography, population, politics, events etc)
    - the state and location of friendly elements
    - the status and location of threats whether natural or man-made
    - the understanding of their potential effects in the near future
    - the understanding of what those factors mean, particularly when integrated together in relation to the Canada COM's mission and goals

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

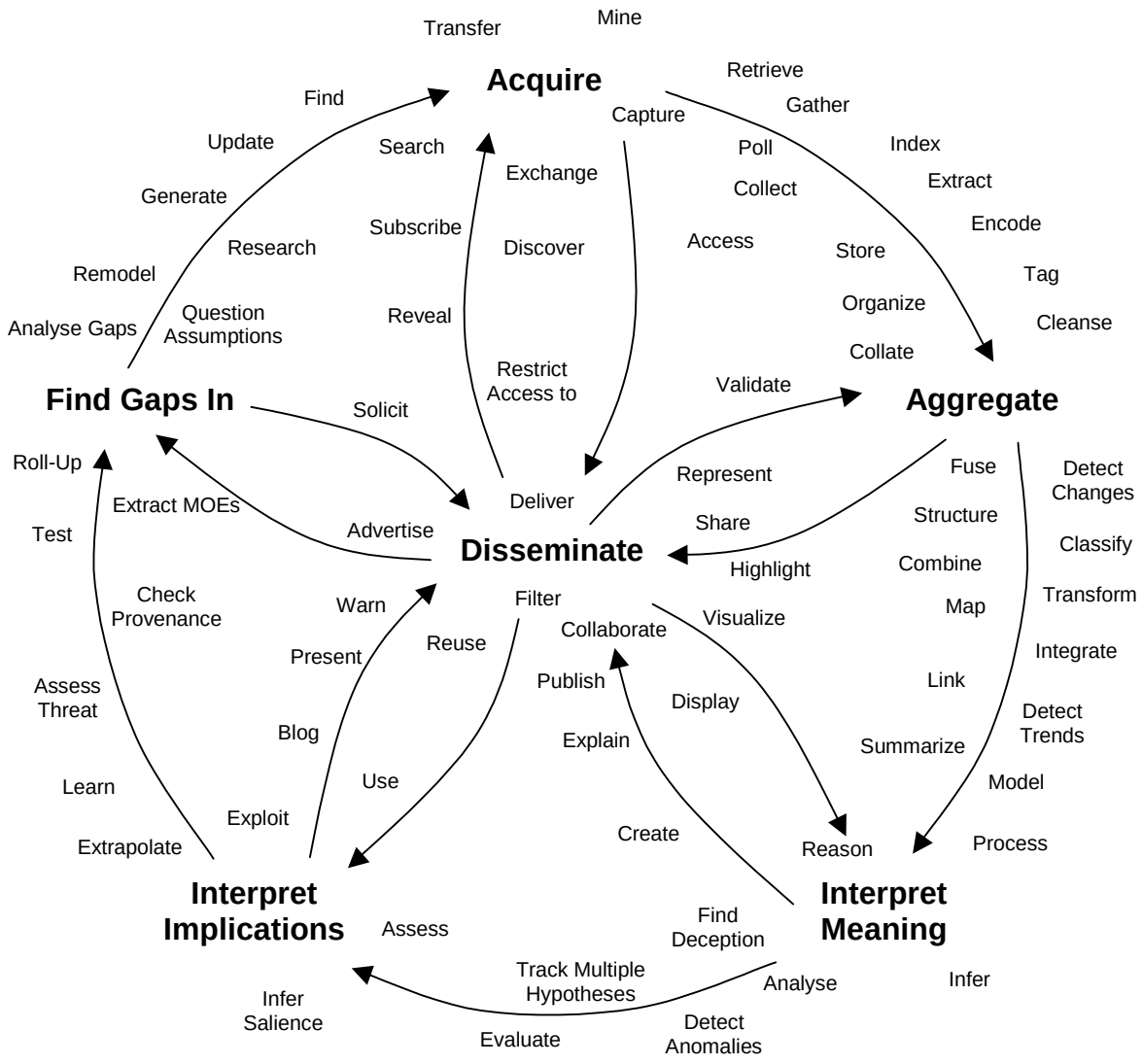

Figure 1-2 Knowledge Management and Exploitation Topics

Rather than define the extent of Knowledge Management and Exploitation (KME), DRDC has identified representative examples of KME topics and activities [ref R-11 pg 13]. This sketch shows those topics in terms of six core KME activities: acquiring, aggregating, interpreting the meaning of, understanding the implications of, recognizing gaps in, and disseminating. It also resembles the classic Intelligence cycle, except that the "dissemination" action has been drawn at the center of the diagram to reflect current trends toward a greater level of sharing at all stages of processing. Because individuals and agencies collaborate in all of these KME activities, all the activities include some form of knowledge dissemination, as represented by the arrows in and out of the center.

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

1.2 The CKEF Contract

The following subsections summarize the CKE-4-MDA project, the CKEF Contract, and two key deliverables of the CKEF Contract.

1.2.1 Technical Vision for the CKE-4-MDA Project

The objective of the CKE-4-MDA project is "to explore and develop an integrated collaborative knowledge exploitation technology framework to allow operators to quickly find, access, create, organize, share, use and reuse relevant knowledge for maritime domain awareness in the ops centres of the JTFA/JTFP and Canada COM headquarters" [ref R-14 pg 3]

Desired outcomes include [ref R-14 pg 4, 5]:

- Identification of current CKE requirements for MDA and extrapolation to address future, anticipated needs
- Identification of the state-of-the-art in KME
- National and international perspectives
- Current technologies and systems:
  - Improvements to better address the needs of the future
- Next generation technologies and systems:
  - Advice on how they can be adopted or adapted into operational systems
- Valid, independent, unbiased recommendations on:
  - The best use of all these technologies
  - The associated concept of operations
  - Potential integrated solutions to CF future needs
- New functionality demonstrated and evaluated on testbed systems
- Validated and robust system/performance specifications informed by the findings and results of the demonstration activity
- Contribution to bringing the industry to the next generation of semantic-based knowledge management and exploitation systems
- Reusable collaborative KME software/technology components

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

1.2.2 CKEF Contract

The objectives of this contract are [A-1 pg 17] to use state-of-the-art technologies to design, implement, and demonstrate:

- an integrated CKEF to allow operators to quickly find, access, create, organize, share, use and reuse relevant MDA knowledge assets in the operational context of RJOC(A), RJOC(P), and JCC, as described in Section 1.2.1;
- a knowledge mapping application ("K-Mapper"), exploiting the CKEF capabilities and specific to the regional joint operations centres and JCC, as described in Section 1.2.4.

The CKEF contract is structured as twelve activities, grouped into two parts.

Part 1 defines the CKEF and the JCC/RJOC(A)/RJOC(P)-specific knowledge mapping application; it identifies the knowledge assets that need to be considered, the KME opportunities for the JCC/RJOC, and the technologies for formal representation of the knowledge for the CKEF.

Part 2 will implement the CKEF and its JCC/RJOC(A)/RJOC(P)-specific knowledge mapping application; it implements the ontology required for the CKEF and its K-mapping application, and then plans, designs, implements, and tests the CKEF and k-Mapper, as sketched in Figure 1-3. The interdependence between activities can be summarized as follows:

Activity 1.1.1: Analysis of Background Documentation: Assemble and read CF documents to achieve a preliminary capture of relevant knowledge assets (KAs). Outputs go to the following activity:

- **to 1.1.3:** list of documented knowledge assets to go in the inventory
- **to 1.2:** list of documented knowledge assets to help identify KME opportunities

Activity 1.1.2: Elicitation of Key Knowledge Assets: Observe RJOC(A), RJOC(P), and JCC operators and perform interviews to determine what knowledge assets they use. Outputs go to the following activities:

- **to 1.1.3:** lists of observed knowledge assets to go in the KAI
- **to 1.2:** interview notes and lists of known KME opportunities as reported by the CF operators
- **to 2.1:** interview notes and lists of maritime domain awareness "concepts" that can be represented in the Ontology, even if they can't be in the KAI

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

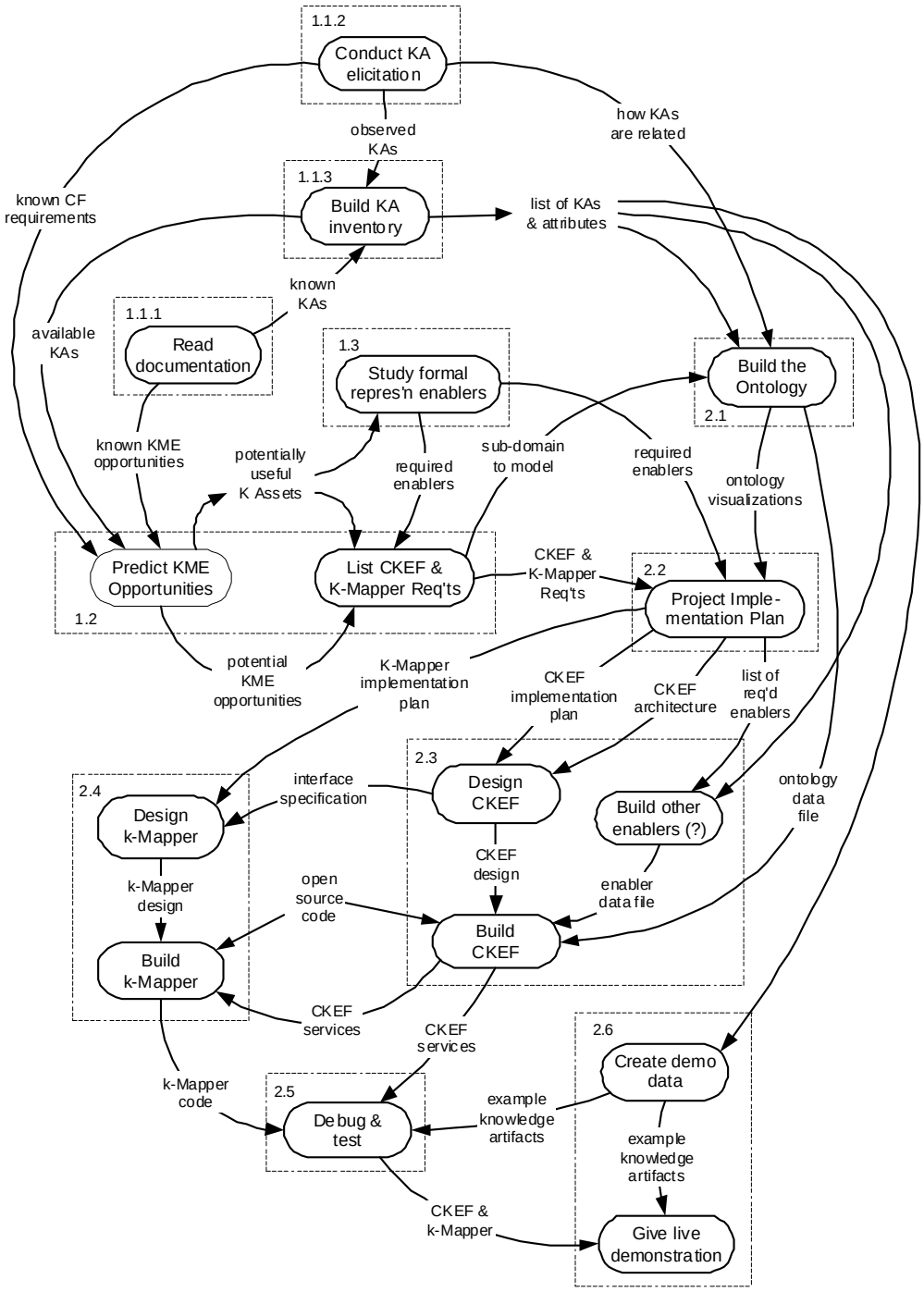

Figure 1-3 Data Flow Diagram and the Interdependence between Activities

Ovals show tasks within the CKEF contract, and the lines show the information dependence between the tasks. The dashed boxes mark numbered Activities from the contract. Explanations of the acronyms and more details about the deliverables from each Activity and their interdependence are given in the text.

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

Activity 1.1.3: KAI: Create a database describing the observed knowledge assets and write a document listing them all, and their attributes. Outputs go to the following activities:

- **to 1.2:** list of knowledge assets that could be used to meet future KME opportunities
- **to 2.1:** list of knowledge assets, including extensive information about how they are linked together, suitable for use as a foundation for the ontology
- **to 2.1:** list of knowledge assets suitable for encoding using one of the other "formal representation enablers" if necessary
- **to 2.6:** description of the types of knowledge assets and their typical attributes, with references to interviews etc. suitable for use in building demonstration data sets

Activity 1.2: Knowledge Management Requirements for RJOC(A), RJOC(P), and JCC: Identify and document current and potential future opportunities for KME at the JCC, RJOC(A), and RJOC(P) in support of maritime domain awareness and identify the resulting requirements of the CKEF and K-Mapper. Outputs go to the following activities:

- **to 1.3:** list of potentially useful KAs, to be used in identifying representation enablers for those KAs
- **to 2.1:** summary of what KME opportunities at the RJOC(A), RJOC(P), and JCC will be supported by the CKEF, and hence what needs to be modeled by the ontology
- **to 2.2:** list of the CKEF and K-Mapper requirements that need to be supported by the CKEF architecture

Activity 1.3: Comparative Study of Formal Knowledge Representation Enablers for the Collaborative Knowledge Exploitation Framework: Identify formal representations, standards, formats, products, or technologies that can be used to represent knowledge, and its inter-relationships. Outputs go to the following activities:

- **to 1.2:** list of useful representation enablers, to be used in specifying the requirements that will be met by the CKEF
- **to 2.2:** list of representation enablers that are required for the CKEF and hence should be included in the CKEF architecture

Activity 1.4: Final Report and Presentation: A summary report from all activities in Part 1 and a presentation for the Go/No-Go meeting.

Activity 2.1: Implementation of the Ontology Required for the CKEF and its K-mapping Application: Build an ontology, or modify a pre-existing one, to

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

represent the contents of the KAI and the concepts observed at the RJOC(A), RJOC(P), and JCC. Outputs go to the following activities:

- **to 2.2:** visualizations of the RJOC(A), RJOC(P), and JCC ontology, suitable to guide the CKEF architects
- **to 2.3:** ontology data file in a form readable by the CKEF so that the CKEF can provide services based on the ontology information

Activity 2.2: Production of the Project Implementation Plan: Create a detailed architecture document and product implementation plan for the CKEF and K-Mapper. Outputs go to the following activities:

- **to 2.3:** CKEF implementation plan, to guide CKEF design
- **to 2.3:** architecture to be implemented in the CKEF
- **to 2.3:** plan indicating which knowledge representation enablers (besides the Ontology) need to be implemented
- **to 2.4:** K-Mapper implementation plan, to guide K-Mapper design

Activity 2.3: Design and Implementation of the CKEF: Implement the CKEF on a service oriented architecture (SOA) using open-source components where available. Outputs go to the following activities:

- **to 2.4:** interface specifications for the services provided by the CKEF
- **to 2.4:** CKEF services that can be used by K-Mapper
- **to 2.5:** CKEF services to be tested

Activity 2.4: Design and Implementation of the Knowledge Mapping Application: Implement the k-Mapping application using CKEF services and other open-source tools and resources. Outputs go to the following activity:

- **to 2.5:** K-Mapper software to be tested

Activity 2.5: Debugging and Testing of the CKEF and the Knowledge Mapping Application: ensure that the CKEF and K-Mapper work, and collect measurements and metrics on their performance. Outputs go to the following activity:

- **to 2.6:** working code to be used in the final demonstration

Activity 2.6: Final Report, Presentation, and Live Demonstration: prepare a demonstration, present the results and demonstrate K-Mapper to various stakeholders. Outputs go to the following activity:

- **to 2.5:** script and example knowledge artifacts (the ones that will be used in the demonstration) to be tested, validated, and debugged

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

1.2.3 The Collaborative Knowledge Exploitation Framework

The core deliverable for this contract will be the CKEF, which will provide a set of essential services for the CKE-4-MDA research project, as illustrated in Figure 1-4. These CKEF services, together with instructions for their use, will be a set of "building blocks" from which KME applications for maritime domain awareness can be built.

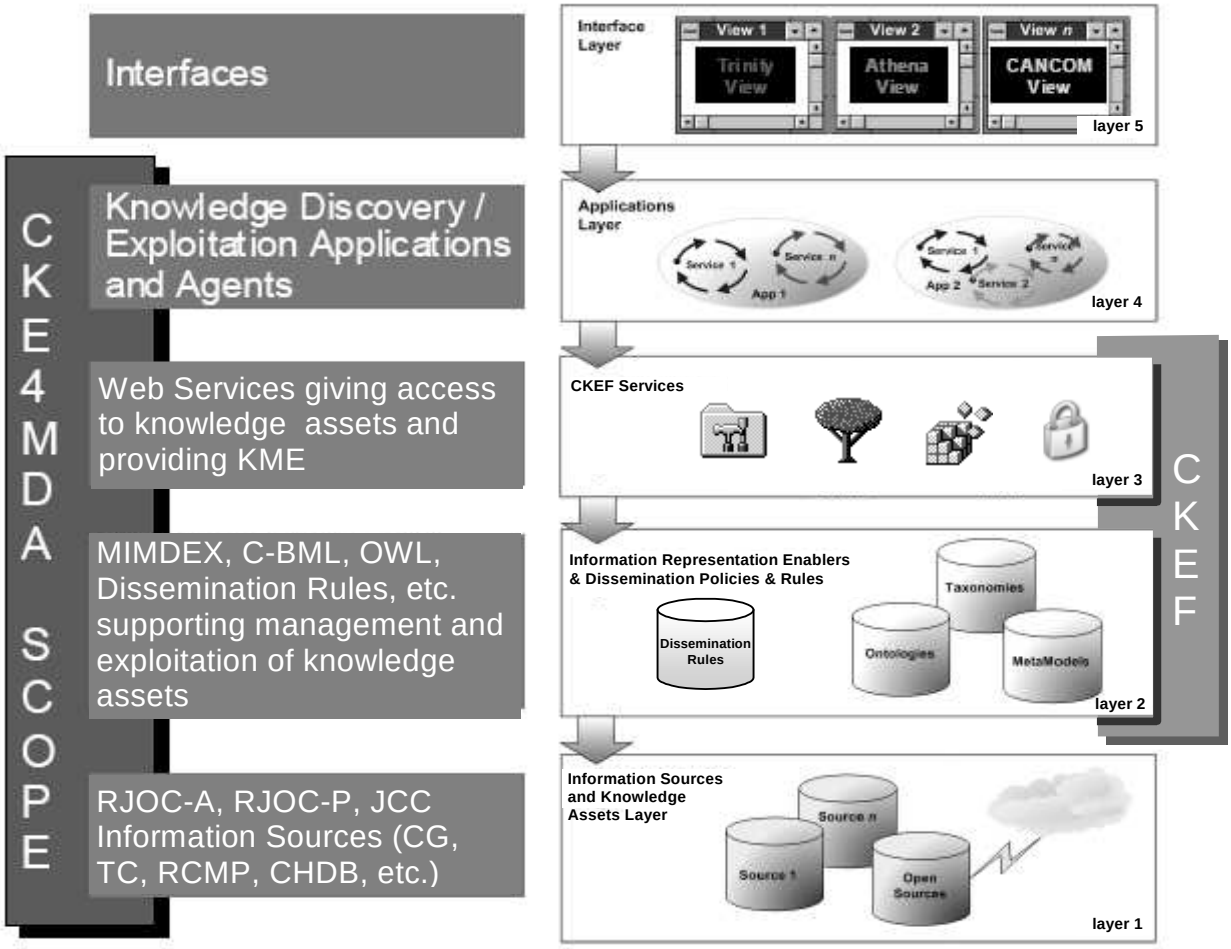

Figure 1-4 Scope of CKEF in CKE-4-MDA

The CKEF will be the framework for the CKE-4-MDA Research Project. The CKEF will provide key services, in an architecture similar to this, for subsequent KME application with For this contract, the CKEF will include (layer 2 of this diagram) information about RJOC(A), RJOC(P), and JCC knowledge assets and their inter-relationships, encoded using at least one representation enabler—an ontology. The CKEF will deliver that information to applications using a number of web services (layer 3). Although only one application (layer 4), the k-Mapper, will be built in this contract as a set of services (layer 3), CKEF services will be engineered to support a broad range of future KME applications. One user interface (layer 5) will be built for K-Mapper. A thin layer of knowledge atoms (layer 1) will be created for use in the final demonstration. [This figure is based on A-1 pg 20].

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

The CKEF services and the knowledge representation enablers supporting them, will be selected based on present and anticipated opportunities for KME services (Activity 1.2).

In this contract, the CKEF will not provide interfaces to actual operational knowledge atoms. A small set of simulated knowledge atoms (e.g. a ship track, an intelligence summary report, etc.) may be created for the purposes of debugging and demonstrating the CKEF services.

1.2.4 The Knowledge Mapping Application

A new knowledge mapping methodology and a conceptual model have been developed at DRDC Valcartier [ref R-13]. This conceptual model will be investigated and used in the CKEF Contract to develop K-Mapper and as a reference to capture and organize the KME opportunities from the RJOC(A), RJOC(P), and JCC stakeholders. The envisioned knowledge mapping application (titled “K-Mapper") will use the CKEF services to exploit the CKEF knowledge representation enablers and knowledge exploitation technologies.

A key feature of K-Mapper is that it will allow the operator to adjust visualization of knowledge assets to highlight one or more of the following four “dimensions” of the knowledge domain:

- **Social Dimension:** links between people, for example in organization charts or common professional activities
- **Process Dimension:** knowledge about activities, including associations between activities such as one activity requiring as input the output from another activity
- **Conceptual Dimension:** describes and connects ideas around a topic, in our case maritime domain awareness. Taxonomies or ontologies can be used to perform conceptual mapping
- **Artefact Dimension:** the implemented “shape” or “structure” of knowledge assets, including for example if an asset is part of a larger asset (membership) or if access to an asset is restricted in some way (dissemination rules)

1.3 The Contract Team

The customer for this project is DRDC Valcartier, represented by the following staff:

- Jean Roy (Scientific Authority)
- Regine Lecocq
- Dr. Alain Auger

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

The prime contractor is MacDonald Dettwiler and Associates Ltd., including the following staff:

- Dr. Harold Zwick (Project Manager)
- Christian Nadeau (Deputy Project Manager)
- Dr. Mike Davenport (RJOC(A), RJOC(P), and JCC Analysis Team Leader)
- Gary Reedel (Ontology Team Leader)
- Gavin Ha (Analyst)

Our domain expert for CF command structure and Maritime Domain Awareness is:

- Andrew Zdunich (CEO of Catalyst Capabilities International)

Human factors and interview expertise were provided by Human Systems Inc., including:

- Dr. Michael Matthews (team leader)
- Lisa Rehak (Analyst)
- Roy Keeble

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

THIS PAGE INTENTIONALLY LEFT BLANK

Use, duplication, or disclosure of this document or any of the information
contained herein is subject to the restrictions on the title page of this document.

2 KR ENABLER REQUIREMENTS ANALYSIS

The objectives of this activity, as stated in the contract [A-1] are to:

"… identify the best means to represent this knowledge in the CKEF. The Contractor shall identify the best candidate knowledge representation (KR) enablers to be used in the CKEF, in accordance with the KM requirements for the RJOC(A), RJOC(P), and JCC, as identified in Activity 1.2. These enablers might include, but shall not be limited to, ontologies, taxonomies, data models, and rules. The knowledge assets shall be later formally represented in the CKEF and the k-mapping application using these KR enablers

In parallel to investigating possible KR enablers, there has been a task to develop KME requirements for RJOC(A), RJOC(P), and JCC, regarding the creation and maintenance of Maritime Domain Awareness (MDA), identified in a parallel activity of the CKEF contract, and described in A-3.

A description of the history of Knowledge Representation is available on Wikipedia. (http://en.wikipedia.org/wiki/Knowledge_representation) Research in knowledge representation is active in both cognitive science and computer science. Cognitive science is concerned with how people store and process information. In computer science, the primary aim is to store knowledge so that programs can process representations consisting of explicit objects, and assertions or claims about them. Representing knowledge in such explicit form enables computers to draw conclusions from knowledge already stored.

Another good overview of the role of Knowledge Representations is available in a paper by Davis, Shrobe and Szolovits [R-26], called "What is a Knowledge Representation?" One role emphasized for a knowledge representation is the need for efficient computation.

For the CKEF we are looking for knowledge representations that will support the information and knowledge about the problem domain to be represented in a declarative

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

fashion. This will allow the operators to expand the system by adding more definitions or relationship information. Technologies under development for the semantic web provide many capabilities applicable to the CKEF.

2.1 Requirements for Knowledge Representation

The CKE-4-MDA domain can be characterized as requiring the users and systems supporting them to understand complex relations involving many different types of objects, the relations between the objects will be revealed incrementally and not all knowledge or understanding will be known.

The structure of the knowledge to be represented includes the following:

- Many different types of objects
- Relations between two objects
- Complex relations involving several objects
- Only some but not all properties of an object are known
- Temporal relations or properties of objects
- Spatial relations or properties of objects
- Uncertainty on the relations or properties of objects
- The environment has non-monotonic logic behaviour since the addition of new knowledge can cause revision of what was previously believed as true.
- Knowledge representation should support automated reasoning

In addition to the above, the knowledge representation will also have to support operational needs to:

- Create a knowledge base for the CKEF
- Update and preferably visually review the knowledge base
- Support offline persistence of the knowledge base
- Query of the knowledge base
- Check consistency of the knowledge base
- Support web services to access the knowledge base

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

2.2 Background

In this section, we discuss some background information in knowledge representation that we view as applicable to the CKEF domain. Specifically, we will cover the Semantic Ontology Spectrum, Resource Description Framework (RDF), and the Web ontology Language (OWL).

2.2.1 Semantic Ontology Spectrum

Even in a specific domain, knowledge representation on a large scale requires more than a consistent controlled vocabulary to extract meaningful information from a knowledge base. Knowledge consists of more than just artefacts it also consists of relationships, actions, time and beliefs. According to Russell and Norvig in R-17, a general framework of concepts in an upper ontology containing general concepts can be expanded with specific concepts to suit the domain of interest.

Currently there is a series of increasingly expressive definitions for data elements in knowledge representations, especially for machine use.

At the low end of the spectrum is a simple binding of a single word or phrase and its definition. At the high end of the spectrum is a full ontology that specifies relationships between data elements using precise URLs for relationships and properties. This series of definitions has been called the semantic or ontology spectrum. A description of it is available at http://en.wikipedia.org/wiki/Semantic_spectrum. This is shown in Figure 2-1 from a presentation by Leo Obrst. The challenge associated with this spectrum is deciding for each particular application, the tradeoffs between increased expressiveness of semantics and decreased efficiency from computation.

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

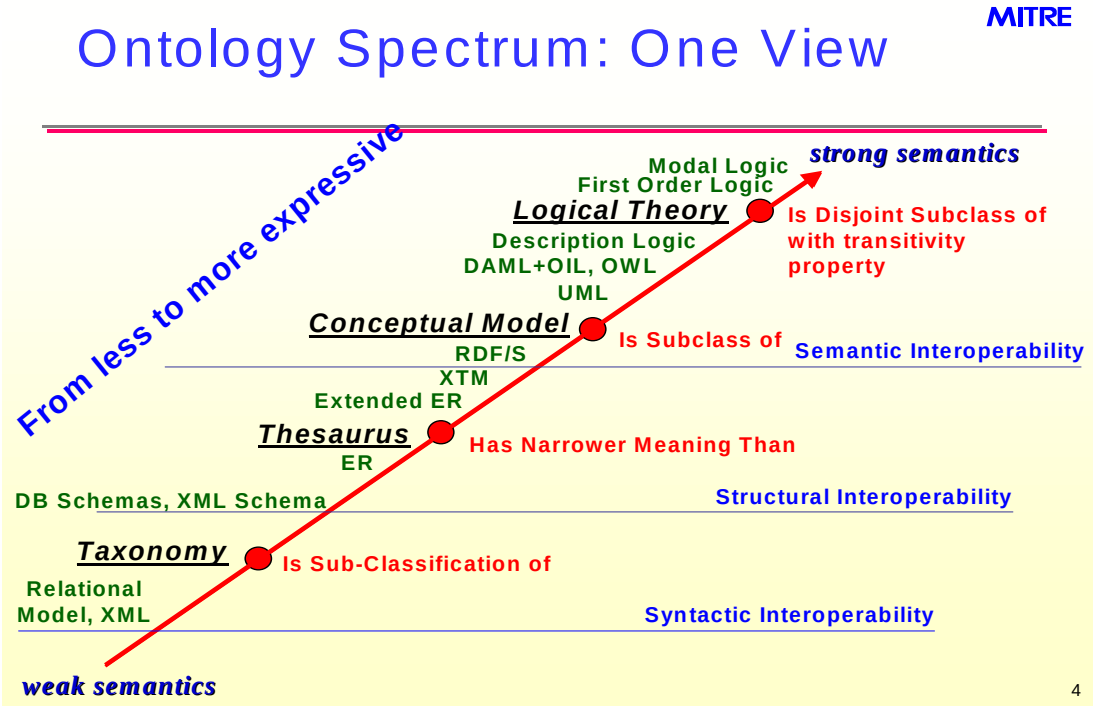

Figure 2-1 Semantic Ontology Spectrum (Ref R-18)

2.2.2 Resource Description Framework (RDF)

The Resource Description Framework (RDF) has been adopted by the W3C as a standard for representing metadata on the Web. Resources in RDF are identified by Uniform Resource Identifiers (URIs) that provide globally-unique and resolvable identifiers for entities on the Web, yielding a decentralized information space. These resources are described through participation in relationships. Relationships in RDF are called Properties and are binary relationships connecting resources to other resources or resources to Literals, i.e., literal values such as Strings or Numbers. These binary relationships are encoded as triples of the form (Subject, Property, Object), which denotes that a resource – the Subject – has a Property whose value is the Object. These triples are referred to as Statements. We call a set of triples an RDF graph, as RDF data can be represented as a directed, labelled graph with typed edges and nodes.

Several formalized methods of expressing RDF for ontologies have been defined. These include the Resource Description Framework Schema (RDFS) and the Web Ontology Language (OWL). RDFS is the simplest formal representation syntax of RDF triples. RDF Schema (RDFS) provides a standard vocabulary for describing the classes and relationships used in RDF statements and consequently provides the capability to define ontologies. RDFS allows us to define hierarchies of class and property types, and it allows us to define the domain and range of property types.

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

2.2.3 Web Ontology Language (OWL)

OWL contains all the features of RDFS and more complex representations. OWL consists of three main sets of syntax classes: OWL Lite, OWL Description Logic (DL) and OWL Full.

- *OWL Lite* supports those users primarily needing a classification hierarchy and simple constraints. For example, while it supports cardinality constraints, it only permits cardinality values of 0 or 1
- *OWL DL* includes all the constructions of OWL Lite plus some additional constructions. *OWL DL* supports those users who want the maximum expressiveness while retaining computational completeness (all conclusions are guaranteed to be computable) and decidability (all computations will finish in finite time). OWL DL includes all OWL language constructs, but they can be used only under certain restrictions (for example, while a class may be a subclass of many classes, a class cannot be an instance of another class). OWL DL is so named due to its correspondence with desription logics. There are reasoners available for OWL-DL.
- *OWL Full* is meant for users who want maximum expressiveness and the syntactic freedom of RDF with no computational guarantees. Reasoning support for the OWL Full does not currently exist.

OWL Full can be viewed as an extension of RDF, while OWL Lite and OWL DL can be viewed as extensions of a restricted view of RDF. Every OWL (Lite, DL, Full) document is an RDF document, and every RDF document is an OWL Full document, but only some RDF documents will be a legal OWL Lite or OWL DL document. Because of this, some care has to be taken when a user wants to migrate an RDF document to OWL. When the expressiveness of OWL DL or OWL Lite is deemed appropriate, some precautions have to be taken to ensure that the original RDF document complies with the additional constraints imposed by OWL DL and OWL Lite.

2.2.4 Non Monotonic Reasoning

From Wikipedia, the free encyclopedia

A **non-monotonic logic** is a formal logic whose consequence relation is not montonic. Most studied formal logics have a monotonic consequence relation, meaning that adding a formula to a theory never produces a reduction of its set of consequences. Intuitively, monotonicity indicates that learning a new piece of knowledge cannot reduce the set of what is known. A monotonic logic cannot handle various reasoning tasks such as reasoning by default (facts may be known only because of lack of evidence of the contrary), abductive reasoning (facts are only deduced as most likely explanations), reasoning about knowledge (the ignorance of a fact must be retracted

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

when the fact becomes known), and belief revision (new knowledge may contradict old beliefs).

Default reasoning

An example of a default assumption is that the typical bird flies. As a result, if a given animal is known to be a bird, and nothing else is known, it can be assumed to be able to fly. This fact must however be retracted if it is later learned that the considered animal is a penguin. This example shows that a logic that models default reasoning should not be monotonic. Logics formalizing default reasoning can be roughly divided in two categories: logics able to deal with arbitrary default assumptions (default logic, defeasible logic, and answer set programming) and logics that formalize the specific default assumption that facts that are not known to be true can be assumed false by default (closed world assumption and circumscription).

Abductive reasoning

Abductive reasoning is the process of deriving the most likely explanations of the known facts. An abductive logic should not be monotonic because the most likely explanations are not necessarily correct. For example, the most likely explanation for seeing wet grass is that it rained; however, this explanation has to be retracted when learning that the real cause of the grass being wet was a sprinkler. Since the old explanation (it rained) is retracted because of the addition of a piece of knowledge (a sprinkler was active), any logic that models explanations is non-monotonic.

Reasoning about knowledge

If a logic includes formulae that mean that something is not known, this logic should not be monotonic. Indeed, learning something that was previously not known leads to the removal of the formula specifying that this piece of knowledge is not known. This second change (a removal caused by an addition) violates the condition of monotonicity. A logic for reasoning about knowledge is the autoepistemic logic.

Belief revision

Belief revision is the process of changing beliefs to accommodate a new belief that might be inconsistent with the old ones. In the assumption that the new belief is correct, some of the old ones have to be retracted in order to maintain consistency. This retraction in response to an addition of a new belief makes any logic for belief revision to be non-monotonic. The belief revision approach is alternative to paraconsistent logics, which tolerate inconsistency rather than attempting to remove it.

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

2.2.5 Truth Maintenance Systems

From Wikipedia, a definition of truth maintenance:

A **truth maintenance system**, or **TMS**, is a knowledge representation method for representing both beliefs and their dependencies. The name *truth maintenance* is due to the ability of these systems to restore consistency.

Many kinds of truth maintenance systems exist. Two major types are single-context and multi-context truth maintenance. In single context systems, consistency is maintained among all facts in memory (database). Multi-context systems allow consistency to be relevant to a subset of facts in memory (a context) according to the history of logical inference. This is achieved by tagging each fact or deduction with its logical history. Multi-agent truth maintenance systems perform truth maintenance across multiple memories, often located on different machines. Further details available at http://en.wikipedia.org/wiki/Truth_maintenance_systems.

2.3 Related Work

Currently there are a lot of research projects that we view as technically very applicable to the CKEF. These projects are investigating approaches for querying knowledge, reasoning on knowledge, and temporal and spatial integration of knowledge. In the following sections, we introduce some projects and state their choices of knowledge representations to meet their goals.

2.3.1 Ontology-based Rules

A position paper on Using Ontology-based Rules for Situation Awareness and Information Fusion [R-19] written by C. Matheus deals with similar domain information as would be required within the CKEF. The situation awareness example used within the paper deals with complex relations involving several objects that have a temporal and spatial property. They use DAML/OIL for representing their ontology and using the Semantic Web Rule Language (SWRL) for constructing rule-based domain knowledge on top of OWL ontologies. They described several significant challenges in trying to develop systems that involved SWRL rules defined over OWL ontologies. Two challenges were

- The restriction to binary predicates in both SWRL and OWL – leads to convoluted rules when dealing with complex relations.
- Dealing with time under monotonicity constraints.

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

In a subsequent paper [R-20], they describe developing a situation awareness application for a supply logistics scenario using SWRL and OWL to represent pertinent domain knowledge and apply it to simulated data using forward chaining inference engines. They describe several challenges in applying SWRL to this problem including foremost the language's limitation to binary predicates and the lack of tools for editing and checking SWRL rules. They describe a manual method for systematically converting the n-ary predicates into classes representing the predicates and collections of properties to associate values of the higher-arity terms with the predicate's class. Separate from the SWRL challenges, they built their own Rete-based inference engine, BaseVISor, which was optimized for the processing of triples and incorporated support for uncertainty reasoning. This engine is based on JESS. BaseVISor is available for research purposes from http://www.vistology.com/basevisor.

In a third paper from C. Matheus [R-21], they describe further capabilities of the BaseVISor. It is a forward-chaining inference engine based on a Rete network optimized for the processing of RDF triples. BaseVISor has been outfitted to process RuleML and R-Entailment rules (rather than the SWRL rules which they had been using in the past). In the case of RuleML, n-ary predicates are automatically translated into binary predicates and reified statements that encapsulate the n-ary predicates' arguments.

These papers all highlight the difficulty of properly specifying and debugging rules defining complex relationships. The CKEF will need to provide support for complex rules. The tradeoff between sufficient expressive power and efficient reasoning support will be a key architectural decision.

2.3.2 Supporting What, Where and When Queries?

The spatial and temporal dimensions are critical aspects of the Maritime Domain Awareness. A number of researchers are currently working on defining and specifying mechanisms to integrate temporal and spatial relationships with the existing semantic models.

In a 2005 paper called Temporal RDF [R-22], Claudio Gutierrez et al present a framework to incorporate temporal reasoning into RDF, yielding temporal RDF graphs. Within temporal RDF graphs, time is modeled with absolute time and time is a temporal label. Temporal labels are associated with statements using RDF reification. The paper also describes an inference method for temporal RDF graphs.

This work has been used and integrated by a group working at the LSDIS Lab at the University of Georgia and the kno.e.sis Centre at Wright State University. This group has written a number of papers [ref R-23, R-24, R-25] explaining their work to integrate time events and geographic information into a RDF store. The most current paper [R-

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

25] from April 2007, addresses problems of both data storage and operator design and implementation.

Specifically, the contributions of this paper are:

- A storage and indexing scheme for spatial and temporal RDF data
- An efficient treatment of temporal RDFS inferencing
- The definition of four spatial and temporal query operators
- An efficient implementation of the defined query operators in Oracle DBMS
- A performance study using a large, synthetically-generated RDF dataset

The implementation builds upon Oracle's Semantic Data Store that provides the capabilities to store, infer, and query semantic data, which can be plain RDF descriptions and RDFS based ontologies.

The temporal and spatial extensions are not dependent upon the use of the Oracle Relational Database Management System (RDMS). The Oracle RDMS had mechanisms for spatial computation, which made the implementation easier but these extensions would work with other RDF data stores.

2.3.3 Query languages for the Semantic Web

In 2006, an article called, RDF Querying: Language Constructs and Evaluation Methods Compared [R-27] was published. The description from the abstract states:

"This article is firstly an introduction into query languages for the Semantic Web, secondly an in-depth comparison of the languages introduced. Only RDF query languages are considered because, as of the writing of this paper, query languages for other Semantic Web data modeling formalisms, especially OWL, are still an open research issue, and only a very small number of, furthermore incomplete, proposals for querying Semantic Web data modeled after other formalisms than RDF exist. For this article, the following RDF query languages have been, admittedly subjectively, selected: Firstly, the "relational" or "pattern-based" query languages SPARQL, RQL, TRIPLE, and Xcerpt; secondly the reactive rule query language Algae; thirdly and last the "navigational access" query language Versa."

The article stated that it was quite clear that the research community has not yet settled on a dominant paradigm to querying Semantic Web data and that this field of research is changing quite quickly.

The absence of mature query languages for OWL ontologies must be considered during the design of the CKEF architecture. The SPARQL query language operating on RDF metadata was capable of supporting most of the query types reviewed in the article.

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

2.3.4 Personal Information Management

There is on going research in investigating ways of improving the current desktop infrastructure for handling information-oriented activities. This research is very similar to the goals of the CKEF and results need to be tracked for possible synergy in KR enablers. Applications under development include:

- HAYSTACK – An MIT program building a collection of tools that allow composing reuseable fragments of information from the Semantic Web and the operations that manipulate them into a task workspace tailored to the user and the task. RDF has been used as the datastore. Further description is available at http://haystack.lcs.mit.edu/
- GNOWSIS – A DFKI program that has a vision of the Semantic Desktop – a Semantic Web enhanced desktop environment. Central is the idea of taking know-how from the Semantic Web to tackle personal information management. The architecture is based on a Semantic Web Server running as Desktop service. Existing desktop applications (email client, browser, office applications) are integrated. The semantic glue between them is expressed with ontologies. The architecture is envisioned to create tools for information management faster and cheaper. Based on the local Semantic Desktop Servers, teams of knowledge workers can set up peer-to-peer connections. Distributed Organisational Memories can be based on Semantic Desktops. The gnowsis framework is an open source project led by the DFKI that realizes parts of this vision. Further description available at http://gnowsis.opendfki.de/
- MINDRAIDER - MindRaider is a Semantic web outliner. It aims to connect the tradition of outline editors with emerging technologies. MindRaider's mission is to organize not only the content of your hard drive but also your cognitive base and social relationships in a way that enables quick navigation, concise representation and inferencing. MindRaider is trying to help with correlation of information related to particular thought. It starts with your personal resources like files, links, thoughts, friends etc. These resources can be in turn represented as/associated with Concepts that are organized to Notebooks. On top of the Concepts within a Notebook is built a (RDF based) metadata layer that enables MindRaider to provide various Notebook facets (flat/hierarchical/graph-oriented but also semantic based views). Further description is available at http://mindraider.sourceforge.net/
- PIMO - a Personal Information Management (PIM) Ontology for the Semantic desktop. A report describing a solution for PIM is available at http://www.dfki.uni-kl.de/~sauermann/2006/01-pimo-report/pimOntologyLanguageReport.html. This solution builds on top of the GNOWSIS application. The report identifies a number of issues in providing a PIM and describes their approaches for best solutions.

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

These programs all are based on RDF and OWL representations. Discussion of how these programs overlap on desired capabilities of the CKEF need to be further explored with DRDC Valcartier. Depending upon which capabilities or services of CKEF align with the above programs, valuable lessons learnt on architectural decisions could be obtained.

2.3.5 Truth Maintenance

We have found two papers describing approaches for implementing a truth maintenance mechanism when working with RDF structures. This research should be investigated within Part 2 of this Contract.

The first paper, "Inferencing and Truth Maintenance in RDF Schema" [R-28] describes a detailed algorithm for truth maintenance for RDF(S), and compares the performance of its algorithm with that of the naive recomputation approach. Its approach is based on truth maintenance: it tracks all deductive dependencies between statements, and uses this to determine which other statements will have to be removed as a consequence of a single deletion. This approach has the additional advantage of having deductive dependencies available for other tasks, such as business logic and change tracking

The second paper, "A High Performance RDFS Store using a Generic Object Model" [R-29] also discusses a truth maintenance mechanism. This paper reports on an approach to building an RDFS database using the Generic Object Model (GOM). The GOM is an OODBMS application framework and is well-suited to modelling graph data. The GOM RDFS SAIL uses Sesame's generic architecture for storing and querying RDF and implements the Storage And Inference Layer (SAIL). The implementation of the GOM RDFS SAIL consists of an implementation of the Graph API (manipulation of RDF graphs) and an RDFS reasoner used to compute and maintain the closure of the store according to the model-theoretic semantics specified by RDF Model Theory.

The strategy used for inference and truth maintenance is similar to the strategy described in [R-28]. The basic proof maintenance architecture maintains explicit proof chains. Each Statement is classified as either an axiom (always true), an explicit statement (one that was asserted by the SAIL API), or an inferred statement. Inferences are computed during insert and maintained when during statement removal. This approach demonstrates reasonable performance and is extremely fast for stores that anticipate frequent statement removal.

Use, duplication, or disclosure of this document or any of the information
contained herein is subject to the restrictions on the title page of this document.

THIS PAGE INTENTIONALLY LEFT BLANK

Use, duplication, or disclosure of this document or any of the information
contained herein is subject to the restrictions on the title page of this document.

3 ENABLER TECHNOLOGY REVIEW

3.1 Approach

The general approach to the enabler technology review started by conducting a broad survey of the available enabler technologies and products that could be associated with the relevant KME requirements. For some requirements, a large number of technologies and products were available. In this case, some technologies and tools were filtered out based on their level of maturity and the amount of information available for them. For other requirements, little academic or commercial research had been done and only a few relevant technologies and products were available. In this case, all available technologies and products were evaluated in detail.

3.1.1 Review Criteria

The following are the criteria against which the enabler technologies and products are evaluated:

- Technology/Product Type (Open source, academic, commercial)
- Requirement Relevance
- Strengths
- Weaknesses
- Limitations
- Availability of Known Implementations
- Type of licenses

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

For each technology and product evaluated, a reference to the product and any known implementations is provided.

3.2 Knowledge Representation Creation

The creation of an ontology to facilitate the representation of knowledge requires the use of an editor tool for all but the most basic ontologies. Because the use of ontologies for knowledge representation is not yet in widespread use in industry, most of the editor tools come from academia.

For this study we will evaluate Protégé, SWOOP, TopQuadrant TopBraid Composer and Altova SemanticWorks. Four of the more popular ontology editors.

Table 3-1 Protégé Specifications

Tool Name	Protégé
Description	An ontology editor with an extendable platform to support the addition of auxiliary features called plug-ins. Protégé-OWL is tightly integrated with Jena and has an open-source Java API for the development of custom-tailored user interface components or arbitrary Semantic Web services.
Strengths	• Open source • Supports the creation and editing of ontologies specified in RDF and OWL. • Plug-ins can be added for inference. • Plug-ins can be added for visualization. • Widely used for ontology editing. • Native RDF support from the Jena API.
Weaknesses	Not a commercially supported product.
Limitations	Out experience in the past so that Protégé was very slow at loading large ontologies. This has not been confirmed against latest release.
Known Implementations	http://protege.cim3.net/cgi-bin/wiki.pl?ProjectsThatUseProtege
License	Mozilla Public License
References	http://protege.stanford.edu/

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

Table 3-2 SWOOP Specifications

Tool Name	SWOOP
Description	A hypermedia based ontology editing tool. Built upon the OWL API. It was produced by the MIND lab at University of Maryland, College Park, but is now an open source project with contributors from all over.
Strengths	• Open source • Supports the creation and editing of ontologies specified in RDF and OWL. • Plug-ins can be added for inference.
Weaknesses	• Less active support and development than Protégé.
Limitations	• Tool is not actively being supported..
Known Implementations	http://code.google.com/p/swoop/
License	Massachusetts Institute of Technology (MIT) License
References	http://www.mindswap.org/2004/SWOOP/ <http://code.google.com/p/swoop/>

Table 3-3 TopBraid Composer™ Specifications

Tool Name	TopQuadrant TopBraid Composer™
Description	A professional visual IDE tool for Semantic Web ontology and application building/modeling. Composer is an Eclipse-based environment built upon the Jena API. A product of TopQuadrant Ltd in which the Technical Director, Holger Knublauch, is the former design and developer of Protégé-OWL. Closed source
Strengths	• Supports the creation and editing of ontologies specified in RDF Schema and OWL. • Eclipse-based platform allows whole coverage of semantic application development life cycle • Plug-ins can be added for extension of Java development. • Built in visualization for RDF graphs, rule engine, Pellet DL reasoner • Use existing geospatial ontologies for geography/location mapping and querying
Weaknesses	• Approx $1500 US per license and it is closed.

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

Limitations	• No plug-ins can be added for third-party reasoner contributions
Known Implementations	Commercial product from http://www.topbraidcomposer.com/
License	• TopQuadrant Software TopBraid Composer™ License • TopBraid Composer™ Academic License
References	http://www.topbraidcomposer.com/ http://protege.cim3.net/cgi-bin/wiki.pl?TopBraid

Table 3-4 SemanticWorks Specifications

Tool Name	Altova SemanticWorks
Description	An RDF/OWL editor that offers a visual-centric method for design of Semantic Web ontologies. Closed source
Strengths	• Supports the creation and editing of ontologies specified in RDF and OWL. • Semantic (consistency) and Syntax checking for OWL • Appealing, easy-to-use interface for visual designing
Weaknesses	• No built in reasoners • No rule engine.
Limitations	• No inferencing. • No application development capability
Known Implementations	Commercial product from http://www.altova.com/products/semanticworks/semantic_web_rdf_owl_editor.html
License	• Altova Software License, $129 US per license
References	http://www.altova.com/products/semanticworks/semantic_web_rdf_owl_editor.html

3.2.1 Applicable OWL Ontologies

Several OWL ontologies exist today providing useful definitions. The ontologies are:

- A J3CIEDM model http://vistology.com/onts/onts.html
- A Situation Awareness http://vistology.com/onts/onts.html
- A Friend of a Friend http://xmlns.com/foaf/0.1/

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

- Description of a Career http://ramonantonio.net/doac/
- Air Tasking Order http://reliant.teknowledge.com/DAML/ATO_Ontology.owl
- Core Planning Representation http://projects.teknowledge.com/CPR2/cprprotege.pon
- Geospatial Ontology http://ontology.buffalo.edu/smith/
- OTH Gold Message http://www.vistology.com/ont/2004/C2IEDM/C2IEDMTrackCoreOnt.owl

Parts or concepts from these ontologies could be the starting point for building an ontology for the CKEF.

3.3 Knowledge Representation Storage and Querying Tools

Table 3-5 Sesame Specifications

Tool Name	Sesame
Description	Built on RDF framework with support for inferencing and querying. Used on top of storage systems (i.e. relational database or filesystems) and for querying of RDF and RDFS data.
Strengths	• Open Source • Supports the creation and editing of ontologies specified in RDF. • Built in storage and inferencing API. • Built in repository API that stores/allows handling of RDF data such as querying and manipulation. • Java servlets that provide a protocol for repository access over HTTP
Weaknesses	• Unknown
Limitations	• Unknown

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

Known Implementations	**Projects** • Cuypers The Cuypers Multimedia Transformation Engine • DOPE Drug Ontology Project for Elsevier • INWISS Integrative Enterprise Knowledge Portal • KnowledgeWeb Realizing the semantic web • On-To-Knowledge Ontology-driven Knowledge Management (the root of Sesame) • RNA - Reference Network Architecture The RNA project investigates reliable, efficient and affordable digital knowledge-sharing solutions and their applicability in the field of cultural heritage (in the broadest sense). • SEKT Semantically-Enabled Knowledge Technologies • SIMILE **S**emantic **I**nteroperability of **M**etadata and **I**nformation in un**L**ike **E**nvironments • SWAP Semantic Web and Peer-to-Peer • WonderWeb Ontology Infrastructure for the Semantic Web
License	• Sesame BSD license
References	http://www.openrdf.org/doc/sesame2/users/

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

3.4 Knowledge Representation Visualization

The editing tool used to generate an ontology generally have built-in functionality to visualize the ontology. However, Protégé allows the addition of "plug-in" components to help visualize ontologies.

In addition to SWOOP's built-in ontology visualization, we will also evaluate Jambalaya, PROMPTViz and IsaViz as visualization tools for Protégé.

Table 3-6 SWOOP Visualization Specifications

Tool Name	SWOOP
Description	A hypermedia based ontology editing tool. Built upon the OWL API.
Strengths	• Look and feel of a web browser. • Hyperlink navigation.
Weaknesses	Unknown
Limitations	Unknown
Known Implementations	Unknown
License	MIT License
References	http://www.mindswap.org/2004/SWOOP/

Table 3-7 Protégé Jambalaya Visualization Specifications

Tool Name	Jambalaya (for Protégé)
Description	Plug-in visualization tool for Protégé.
Strengths	• Shows the hierarchy of the ontology using tree graphs. • Many tools available for manipulating the view.
Weaknesses	• Tree graphs can become complex and hard to navigate for large ontologies.
Limitations	• Does not show the changes made to the ontology while editing.
Known Implementations	**Jambalaya is included with the "full" version of Protégé.**

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

License	GNU General Public License
References	http://www.thechiselgroup.org/jambalaya http://protege.stanford.edu/conference/2004/abstracts/Storey.pdf

Table 3-8 Protégé PROMPTViz Visualization Specifications

Tool Name	PROMPTViz (for Protégé)
Description	Plug-in visualization tool for Protégé.
Strengths	• Shows the differences between two versions of an ontology. • Provides a tree layout view.
Weaknesses	• Some graphs hard to understand.
Limitations	Unknown
Known Implementations	Included with full Protégé download.
License	Free to use (no license specified)
References	http://www.thechiselgroup.org/?q=promptviz http://protege.stanford.edu/conference/2004/abstracts/Storey.pdf

Table 3-9 IsaViz Visualization Specifications

Tool Name	W3C IsaViz
Description	Visual environment for browsing and creating RDF graphs; used with GraphViz.
Strengths	• 2.5D interface for navigation and zooming in the graph. • Plug-ins to read/write RDF data directly from/to Sesame server
Weaknesses	• May randomly freeze for no apparent reason.
Limitations	• Problems with GraphViz will translate to problems with IsaViz Works only on RDF, N3 and N-triple import.
Known Implementations	Available from W3.org
License	Free to use (no license specified)
References	http://www.w3.org/2001/11/IsaViz/

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

3.5 Knowledge Representation Inferring

There are several rule engines that support inference for RDF that can be applied to the ontologies created in OWL-DL. Inference refers to the process of deriving additional information within an instance of an ontology based on the structure and hierarchy of the ontology definition.

The rule engines evaluated for this study are Jena2, Pellet and RACER.

Table 3-10 Jena2 Specifications

Tool Name	Jena2
Description	An inference API for use with languages like RDFS and OWL that allow additional information to be inferred from instance data and class descriptions.
Strengths	• Open source • Built-in support for RDFS and OWL. • Supports external reasoners conforming to the DL Implementers Group (DIG) standard.
Weaknesses	• No performance tuning applied for OWL implementation. • Still under development. Rule support for OWL is incomplete.
Limitations	• Rule support for OWL is incomplete.
Known Implementations	Built into the Protégé ontology editor.
License	Apache Licence
References	http://jena.sourceforge.net/

Table 3-11 Pellet Specifications

Tool Name	Pellet
Description	An inference API with full support for OWL-DL.
Strengths	• Open source • Conforms to the DIG standard so it can be incorporated into ontology editors such as Protégé and SWOOP. • Can be used in conjunction with Jena or OWL-API.

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

Weaknesses	Pellet supports a subset of SWRL called DL-Safe Rules. **The following SWRL features are not currently supported by Pellet: class atoms with anonymous classes, data valued property atoms, and built-in functions**.
Limitations	Pellet includes an optimized query engine capable of answering ABox queries.
Known Implementations	Built in to SWOOP, Pellet is now commercially supported by Clark & Parsia LLC
License	MIT License
References	http://pellet.owldl.com/

Table 3-12 RACER Specifications

Tool Name	RACER
Description	Reasoning engine for semantic web ontologies developed in OWL. RACER stands for **R**enamed **A**Box and **C**oncept **E**xpression **R**easoner. RacerPro is the commercial name of the software
Strengths	• Conforms to the DIG standard so it can be incorporated into ontology editors such as Protégé and SWOOP.
Weaknesses	• Commercial
Limitations	RacerPro 1.9 does not employ the unique name assumption as required by OWL DL
Known Implementations	available form http://www.racer-systems.com/products/racerpro/index.phtml
License	Commercial
References	http://www.racer-systems.com/

3.6 Rule engines

There is a Initiative to develop a Web language for rules using XML markup, formal semantics, and efficient implementations. The Initiative is called RULEML and can be accessed at http://www.ruleml.org/

Rather than focusing on academic research prototypes, RuleML is about rule interoperation between industry standards (such as JSR 94, SQL'99, OCL, BPMI, WSFL, XLang, XQuery, RQL, OWL, DAML-S, and ISO Prolog) as well as established systems (CLIPS, Jess, ILOG JRules, Blaze Advisor, Versata, MQWorkFlow, BizTalk, Savvion, etc.).

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

The Initiative develops a modular RuleML specification and transformations from and to other rule standards/systems. Moreover, it coordinates the development of tools to elicit, maintain, and execute RuleML rules. RuleML covers the entire rule spectrum, from derivation rules to transformation rules to reaction rules. RuleML can thus specify queries and inferences in Web ontologies, mappings between Web ontologies, and dynamic Web behaviors of workflows, services, and agents

There are two rule engines conforming to the RuleML rules that may be of use to the CKEF for supporting complex task. The two engines are SweetRules and DR-Device.

SweetRules - http://sweetrules.projects.semwebcentral.org/ SweetRules is a uniquely powerful integrated set of tools for semantic web rules and ontologies, revolving around the RuleML (Rule Markup/Modeling Language) emerging standard for semantic web rules, and supporting also the closely related SWRL (Semantic Web Rule Language), along with the OWL standard for semantic web ontologies, which in turn use XML and, optionally, RDF. (SWRL rules are essentially an expressive subset of RuleML rules.) No updates since 2005.

DR-Device - http://iskp.csd.auth.gr/systems/dr-device.html

DR-DEVICE is a system for defeasible reasoning on the Semantic Web.

Defeasible reasoning is a rule-based approach for efficient reasoning with incomplete and inconsistent information. Such reasoning is, among others, useful for ontology integration, where conflicting information arises naturally; and for the modeling of business rules and policies, where rules with exceptions are often used. It can represent facts, rules, and priorities among rules. This reasoning family comprises defeasible logics and Courteous Logic Programs. The main advantage of this approach is the combination of two desirable features: enhanced representational capabilities allowing one to reason with incomplete and contradictory information, coupled with low computational complexity compared to mainstream nonmonotonic reasoning.

DR-DEVICE is capable of reasoning about RDF metadata over multiple Web sources using defeasible logic rules. The system is implemented on top of CLIPS production rule system and builds upon R-DEVICE, an earlier deductive rule system over RDF metadata that also supports derived attribute and aggregate attribute rules. Rules can be expressed either in a native CLIPS-like language, or in an extension of the OO-RuleML syntax. The operational semantics of defeasible logic are implemented through compilation into the generic rule language of R-DEVICE. Papers published in 2006.

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

3.7 Knowledge Representation Querying

SPARQL is the proposed RDF querying language proposed by the W3C. The specification of SPARQL is currently at the draft state (http://www.w3.org/TR/rdf-sparql-query/). SPARQL supports queries consisting of triple patterns, conjunctions, disjunctions and other optional patterns.

Despite its draft state, several tools currently support SPARQL. Both the Jena2 and Pellet rule engines support SPARQL queries.

Both Jena2 and Pellet have already been evaluated in Section3.4 so no additional elaboration will be done.

3.8 Weak Semantic Methods

Table 3-13 defines a set of KR enablers that only have weak semantics.

Table 3-13 Weak Semantic Enablers.

Enabler Type	Description
Folksonomy	Folksonomies are simply the set of terms that a group of users tagged content with. They are not a predetermined set of classification terms or labels.
Controlled Vocabularies	A list of terms that have been enumerated explicitly.
Data Models	Application specific models of the relationships and/or organization of data.
Taxonomy	A collection of controlled vocabulary terms organized into a hierarchical structure such as a tree with parent-child relationships.
Thesaurus	A networked collection of controlled vocabulary terms. It uses associative relationships in addition to or in place of parent child relationships.
Facet Analysis	An organization of a controlled vocabulary into facets (categories/classes) and array (terms). Allows multiple classification of a term so it is generally more flexible than a taxonomy.
Gazetteer	A geographic dictionary containing information about places, place names and geographic features.
Chronology	The arrangement of information based on time.

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

For the CKEF, the core KR will be based on stronger levels of semantic expressiveness since this will provide greater benefits and results to the user by allowing more automated reasoning support. But some of the lesser semantic enablers could still be applicable in a supporting role.

One simple semantic method is provided by Folksonomies (http://en.wikipedia.org/wiki/Folksonomy). The definition from Wikipedia is:

> "A **folksonomy** is a user generated taxonomy used to categorize and retrieve Web pages, photographs, Web links and other web content using open ended labels called tags. Typically, folksonomies are Internet-based, but their use may occur in other content as well. The process of folksonomy tagging is intended to make a body of information increasingly easier to search, discover, and navigate over time. A well-developed folksonomy is ideally accessible as a shared vocabulary that is both originated by, and familiar to, its primary users. Two widely cited examples of websites using folksonomic tagging are Flickr and del.icio.us."

If the CKEF provided a mechanism for users to tag web sites, documents or other sources of information with their own personal terms then some possible search synergies could be obtained.

Although the users may come from the same domain background, the freedom of allowing the users to tag web sites with their own personal terms will produce a variety of terms that will not be suitable for any automated reasoning using these tags. But as shown via the del.icio.us site, a tool that shows the tags that other users have applied to the information you are viewing can lead to new discoveries. Insight can be gained from comparing the tags that others have applied to the same information source as you. Also, insight can be gained from reviewing what information sources other users have tagged when their tag is of interest to you. Although this is a simple and informal mechanism, it may support the discovery of unknown social connections of like-minded people or people with similar domain interest. We should look for ways of including the folksonomy tools within the CKEF, more from the point of view of an experiment than as a necessary enabler.

The next step would be to define controlled vocabularies that restrict the selection of tags or the choices for entering field inputs to values within the vocabulary. Benefits are that there is only a restricted set of values for automated processing but the challenge is developing a vocabulary rich enough to properly cover your domain area and also training the users in the consistent use of the vocabulary.

Several data models like JC3IEDM or AdatP-3 will be very important for defining interfaces to other systems to be able to exchange information. The challenge for knowledge representation is how to fuse information from other systems with our MDA context to generate knowledge. We see these data models supporting inter-operability of system but not as knowledge representations. The models will be reviewed as an input for the development of the ontology.

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

A taxonomy or thesaurus will provide an automated method for expanding searches through the use of synonyms or through expansion to parent/child clarifications. This automated expansion of search terms could be very useful but a richer KR would be even better at it. A KR enabler technology defines a framework for the implementation of a formal KR enabler.

An application of Facet Analysis can be seen by the operation of the desktop Google search tool. As soon as the user starts to enter a search phase, the Google tool provides a list of possible search expressions. If the technique was available to an operator with their search cued off of current domain focus, ontology relationships, Standard Operating Procedures (SOP) parameters, or other operator searches, then it could also provoke new discoveries or enhance searches. Within the K-Mapper, it may be a useful enhancement to the GUI for selection for any of the dimensions for display filtering.

An online Gazetteer can be a very valuable source for resolving place names. It can provide a geographical dictionary that will be used by applications working with geospatial relationships. We see the CKEF using the geographic knowledge representations within its ontology to facilitate the usage of Gazetteers.

Finally, WordNet was evaluated as a resource for a thesaurus type enabler.

Table 3-14 WordNet Specifications

Tool Name	WordNet
Description	A lexical database of the English language that can be used a thesaurus.
Strengths	• Open source • Contains a large collection of words and their synonyms. • Open source interfaces available for WordNet • Can be used in conjunction with other tools for data mining.
Weaknesses	• May not work well in a domain with its own vocabulary.
Limitations	• Cannot readily add your own content to WordNet.
Known Implementations	Mostly research projects related to data mining. Examples: http://citeseer.ist.psu.edu/richardson94using.html
License	Berkeley Software Distribution (BSD)
References	http://wordnet.princeton.edu/

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

3.9 Workflow / Process Knowledge

A workflow is the execution of a work procedure – a work activity carried out by a human or machine. A workflow can be modeled using a workflow language specification. The language specification provides a notation for describing workflows that can be used to graph and/or execute the workflow.

The evaluation for workflow knowledge has been split into two parts: technologies and tools. The technologies are the underlying standard methodologies created to identify and describe workflows. The tools are the products that implement the technologies.

3.9.1 Technology Evaluation

The current workflow language technologies available and assessed for this study include Java Process Description Language (jPDL), Business Process Execution Language (BPEL), BPEL4People and XML Process Definition Language (XPDL).

Table 3-15 jPDL Specifications

Technology Name	Java Process Description Language (jPDL)
Description	A Java process modeling language for Business Process Modeling (BPM) and workflow.
Strengths	• Incorporates both human interactions and web services into the business process flow.
Weaknesses	• No direct support for notation. • Not a standard for business process modeling and workflow. • Limited tool support.
Limitations	• Can only be incorporated in Java applications. • No standards for use of jPDL for business modeling. Tool must develop its own business process data models.
Known Implementations	JBoss Java Business Process Management (jBPM) (http://www.jboss.com/products/jbpm)

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

Table 3-16 BPEL Specifications

Technology Name	Business Process Execution Language (BPEL)
Description	A process modeling specification for describing the interactions between software services.
Strengths	• Process orchestration integrating web services into the business process flow. • Not tied to a specific programming language. • Many tools support BPEL.
Weaknesses	• Provides no support for incorporating user interaction (i.e., decision making). • No direct support for graphical notation.
Limitations	No support for incorporating user interaction.
Known Implementations	JBoss jBPM (http://www.jboss.com/products/jbpm) Apache ODE (http://incubator.apache.org/projects/ode.html) Oracle Business Process Manager (http://www.oracle.com/technology/products/ias/bpel/index.html)

Table 3-17 BPEL4People Specifications

Technology Name	Business Process Execution Language for People (BPEL4People)
Description	An extension to core BPEL to provide support for human interaction with execution of the business process model.
Strengths	• Process orchestration integrating web services into the business process flow. • Not tied to a specific programming language. • Provides support for human interaction in a BPEL business process flow.
Weaknesses	• No direct support for graphical notation. • No tools currently support BPEL4People
Limitations	• No current implementations of BPEL4People • Resistance to the adoption of BREL4People by BPEL tool providers.
Known Implementations	None

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

Table 3-18 XPDL Specifications

Technology Name	XML Process Definition Language (XPDL).
Description	A standard of the Workflow Management Coalition (WMC) to exchange business process management definitions between workflow products.
Strengths	• Defines both the graphics and the semantics of a workflow. • Accepted standard of the WMC.
Weaknesses	• Does not contain the executable steps of the business process. Requires a tool to interpret the model in order to execute it. This tool determines the interface with the web services.
Limitations	• Dependent on supporting tools to determine the support for interaction with web services and human users. • Designed primarily as a representation of the graphics of a workflow.
Known Implementations	Enhydra Shark Workflow (http://www.enhydra.org/workflow/shark/index.html)

3.9.2 Tool Evaluation

The specific tools evaluated for the representation and execution of a workflow are JBoss jBPM jPDL, Apache ODE BPEL, Oracle Business Process Manager BPEL, Enhydra Shark Workflow XPDL and Adobe Livecycle Workflow XPDL.

Table 3-19 JBoss jBPM Specifications

Tool Name	JBoss jBPM
Description	Tool to support the creation of business processes incorporating people, applications and web services.
Strengths	• Open source • Supports a service oriented architecture • Allows the incorporation of people and web services into a business process • Widely used and supported • Supports BPEL and jPDL technologies
Weaknesses	• Build upon a custom jPDL business process model that is not a recognized standard. • Limited support for BPEL (future versions will have better BPEL support).
Limitations	Standard Subscription $2250 US for 1 year

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

License	GNU General Public License
References	http://www.jboss.com/products/jbpm

Table 3-20 Apache ODE Specifications

Tool Name	Apache ODE
Description	Choreograph engine for developing processes that call services based a BPEL definition of the process execution.
Strengths	• Open source • Supports a service oriented architecture • Full support for BPEL
Weaknesses	• Not widely used and still evolving
Limitations	• No support for incorporating people into the business process.
License	Apache License
References	http://incubator.apache.org/ode/

Table 3-21 Oracle Business Process Manager Specifications

Tool Name	Oracle Business Process Manager
Description	Infrastructure for creating, deploying and managing business processes in BPEL
Strengths	• Commercial product. • Supports a service oriented architecture. • Full support for BPEL. • Provides some workflow capabilities that support human interaction.
Weaknesses	• Commercial product.
Limitations	None
License	Commercial
References	http://www.oracle.csom/technology/products/ias/bpel/index.html

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

Table 3-22 Enhydra Shark Workflow Specifications

Tool Name	Enhydra Shark Workflow
Description	Workflow server built upon the XPDL as its native workflow description language.
Strengths	• Open source. • Supports a service oriented architecture. • Full support for XPDL. • Support for human interaction.
Weaknesses	• Not a well supported product (i.e., little documentation or commercial support).
Limitations	Unknown
License	GNU General Public License
References	http://www.enhydra.org/workflow/shark/index.html http://objectwebcon06.objectweb.org/xwiki/bin/UseCase/No3 UC3: viaContext, a web-based knowledge and information management solution using Enhydra

Table 3-23 Adobe Livecycle Workflow Specifications

Tool Name	Adobe Livecycle Workflow
Description	Workflow automation build upon XPDL that incorporates people, systems, documents, business rules, and Web services.
Strengths	• Commercial product. • Supports a service oriented architecture. • Built upon XPDL. • Support for human interaction.
Weaknesses	• Commercial product.
Limitations	Unknown
License	Commercial License
References	http://www.adobe.com/products/server/workflowserver/

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

3.10 Human Expertise Network

A human expertise directory could be built upon a social network that shows not only the people but also the relationships between the people. This section explores the social network technologies and tools available.

A social network is a structure made up of nodes, which represent individuals or organizations, and the relationships between them. There are numerous websites that attempt to build social networks and the major search engines, including Google and Yahoo, have social network building capabilities.

There are few active standards available for social network building and analysis. Friend of a Friend (FOAF) defines an ontology that represents individuals and the relationships between individuals (http://www.foafnet.org, http://www.foaf-project.org/). It is used primarily in the academic world and few or no commercial applications have been built upon it. FOAFCorp is an experimental extension to the FOAF ontology to describe corporate entities and interconnections (http://rdfweb.org/foafcorp/intro.html). Extensible Hypertext Markup Language (XHTML) Friends Network (XFN) is a method of representing human relationship embedded into hyperlinks in webpages (http://www.gmpg.org/xfn/). It is primarily used within blogs in a hyperlinks to other persons web pages to show the blog owner's relationship to that person.

There are numerous products on the web to facilitate the evolution of open social networks. These include websites such as MySpace (http://www.myspace.com) orkut (https://www.orkut.com/) and Yahoo! 360 (http://360.yahoo.com). These sites are open to anyone on the web.

Few open source and commercial products exist at an advanced level of development for the construction and management of closed social networks that would typically be used in a corporation or large institution. IBM recently introduced the Lotus Connections product suite that allows the building and sharing of information on corporate social networks (http://www-142.ibm.com/software/sw-lotus/products/product3.nsf/wdocs/connectionshome). Alternately, Elgg is open social software widely used by academic institutions to build social networks between students and faculty (http://elgg.org/). Neither Lotus Connections nor Elgg appear to be built upon any type of open standards. PeopleAggregator is a social network product free for non-commercial users that is in the process of developing an import/export layer that supports open standards such as FOAF and XFN. However, it is in the early stages of its development (http://peopleaggregator.com).

While all of these products allow the creation of social networks, not all allow you to visualize the networks and its interconnections. FOAFscape is an experimental tool for visualizing social networks that are defined by a collection of FOAF compliant documents (http://foafscape.berlios.de/).

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

http://en.wikipedia.org/wiki/Description_of_a_Career provides a description of a career ontology which is an expansion of FOAF

http://ramonantonio.net/doac/ adds further details on the description of a career ontology and provides an interesting aspect on capturing current and past projects worked on.

Also need to review the Organization meta model within J3CIEDM definition as another input for an ontology describing a social/hierarchical network.

Table 3-24 FOAF Specifications

Technology Name	Friend of a Friend (FOAF) Ontology
Description	An ontology that defines people and the relationships between people (friendships).
Strengths	• Open standard • Can be extended to represent more complicated relationships (i.e., FOAFCorp) using readily available ontology editors like Protégé and Swoop.
Weaknesses	• Core FOAF ontology does not define complicated relationships that may be present in the maritime domain. • Limited commercial or open source tools support. • Mostly academic projects using FOAF.
Limitations	• Few (if any) mature commercial or open source tools that support FOAF.
Known Implementations	FOAFscope browser for visualizing the social network. 'They Rule' corporate network web based editor and navigation tool (http://www.theyrule.net/).
Licensing	Open Standard

Table 3-25 XFN Specifications

Technology Name	XHTML Friend Network (XFN)
Description	A specification for meta tags inserted into hyperlinks in Hypertext Markup Language (HTML) that show relationships between the current web page and the hyperlinked web page.
Strengths	• Open standard • Can be used to represent relationships between the authors of webpages • Could extend to define your own relationships

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

Weaknesses	• Core XFN ontology does not define complicated relationships that may be present in the maritime domain. • No mature commercial or open source tools that support XFN. • Mostly used in personal blogs to create links to friends web pages.
Limitations	• Few (if any) mature commercial or open source tools that support XFN.
Known Implementations	See http://www.gmpg.org/xfn/tools.
Licensing	Open Standard

Given that FOAF is one of the few open standards for social networks, it would probably be the best KR enabler for social networks. The FOAF ontology could be extended to add support for maritime domain assets.

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

4 RECOMMENDATIONS

During the development of this report, we have performed a review of the knowledge representations that are being used today. The review was performed to understand what are the best candidate enabler technologies for the CKEF. Note there might be services that will be identified in Part 2 of this contract that would require different KR enablers than those recommended here, but we are not able to determine it as this point.

The following are our recommendations:

1. The dynamic nature of Maritime Domain Awareness inputs requires that the CKEF KR support both temporal and spatial dimensions. The approach described in [R-25] should be considered.

2. The use of ontologies to capture relationship between objects is being proven with semantic web applications to be a very powerful KR and therefore ontologies should be used in the CKEF.

3. There is a trade-off between increasing the expressive power of the ontology language and efficient reasoning support. As the ontology is being developed in Part 2 of the Contract, the ontology should be evaluated to see what implicit relationships could be inferred. The underlying question is whether the ontology supporting MDA for the RJOCs will have explicit statements from which additional or valuable implicit statements could be inferred.

4. Any COTS component used within the CKEF architecture should conform to Industry standards to maximize inter-operability with other applications and to provide continued enhancement. For this technology, Industry standards would be conforming to W3C Recommendations.

5. Reviewing the experiences of applications currently being developed, the two choices for ontology language are RDF(S) and OWL-DL. RDF(S) is less expressive but has better support for querying and storage and has been extended to support temporal and spatial relationships. While OWL-DL with the existing

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

Pellet reasoning engine is a much more powerful expressive KR for thematic knowledge. With an expectation that CKEF will need to provide a mature query capability, we recommend RDF(S) be used as the ontology language.

6. The choice of the ontology editor is influenced by personal reaction to GUI behaviour. Although SWOOP is not being actively supported, we prefer it to Protégé. All of the ontology editors support exchange of the developed Ontology definitions so the Ontology can be moved from one tool to the other.

7. The absence of mature query languages for OWL ontologies must be considered during the design of the CKEF architecture. The SPARQL query language operating on RDF metadata was capable of supporting most of the query types reviewed in the article. For these reasons, we recommend SPARQL for the Query capability.8. The ontology rule papers [R-19, 20, 21] all highlight the difficulty of properly specifying and debugging rules defining complex relationships. The CKEF will need to provide support for complex rules. The trade-off between sufficient expressive power and efficient reasoning support will be a key architectural decision.

8. The analyst type applications envisioned for the CKEF would benefit from support of a truth maintenance mechanism within the CKEF. The two papers [R-28, R-29] describing approaches for implementing a truth maintenance mechanism when working with RDF structures should be considered within Part 2 of this Contract.

9. For capturing procedures within the CKEF or K-Mapper, we think that a representation supporting workflow rather than Business process engineering will be better. From the capability descriptions, we are recommending open source Enhydra Shark Workflow for further consideration.

10. Given that FOAF is one of the few open standards for social networks, it would probably be the best KR enabler for social networks. The FOAF ontology could be extended to add support for maritime domain assets.

11. For a visualization tool, Graphical Visualization (Graphviz) is a very good open source tool. It is used in both Protégé and CMAP. Its input data structure is a very simple 3-tuple of node-relation-node. We recommend this tool since it is very compatible with the RDF structure and the tool works very well for visual presentation.

12. Finally from the del.icio.us, insight can be gained from reviewing what information sources other users have tagged when their tag is of interest to you. Although this is a simple and informal mechanism, folksonomy tagging may support the discovery of unknown social connections of like-minded people or people with similar domain interest. We should look for ways of including the folksonomy tools within the CKEF, more from the point of view of an experiment than as a necessary enabler.

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

5 DOCUMENTS

5.1 Applicable Documents

A-1	W7701-062549/001/QCL	Development of a Collaborative Knowledge Exploitation Framework (CKEF) for the Maritime Domain Awareness Operations Centres and of a k-Mapping Application Contract. Public Works and Government Services Canada. Jan. 25, 2007.
A-2	01-4484-1	Collaborative Knowledge Exploitation Framework (CKEF) for the Maritime Domain Awareness Operations Centers and a k-Mapping Application Part A – Technical Proposal. Jan. 5, 2007. MacDonald Dettwiler.
A-3	CKEF-RP-52-5276	Maritime Domain Awareness Knowledge Management Requirements. June 8, 2007. MacDonald Dettwiler.

5.2 Reference Documents

R-1 Canada. Privy Council Office, Securing an Open Society: Canada's National Security Policy, ISBN 0-662-36982-3, http://www.pco-bcp.gc.ca/docs/Publications/NatSecurnat/natsecurnat_e.pdf, 2004

R-2 National Defence, Canada's International Policy Statement: A Role of Pride and Influence in the World, DND: ADM(PA), ISBN 0-662-68940-2, http://www.dnd.ca/site/reports/dps/pdf/dps_e.pdf, 2005

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

R-3 Defence R&D Canada, “Technology Investment Strategy,” Ottawa, http://www.drdc-rddc.gc.ca/publications/tis02_e.pdf, 2002

R-4 The Technical Cooperation Program, “MDA Workshop Consolidated Results,” TTCP via DRDC Valcartier, 2006

R-5 Interdepartmental Marine Security Working Group, “Transport Canada's Approach to Marine Security,” Transport Canada, http://www.tc.gc.ca/MarineSecurity/policy/enhancing/approach.htm, January 2004.

R-6 National Defence and the Canadian Forces, “Backgrounder: Canada Command,” http://www.dnd.ca/site/newsroom/view_news_e.asp?id=1692, June 28, 2005

R-7 Canadian Forces, “Canada Command: Draft Concept of Operations,” Version 3, 01 March 2006

R-8 Joint Task Force (Pacific) Headquarters, “Concept of Operations, Joint Task Force (Pacific),” JTFP: 3000-1-3 (J00 COMD), 23 January 2006

R-9 Schreiber, Guus, H. Akkermans, A. Anjewierden, R. de Hoog, N. Shadbolt, W. Van de Velde, and Bob Wielinga, Knowledge Engineering and Management, MIT Press, London, 2000

R-10 The Pocket Oxford Dictionary, Oxford University Press, 1992

R-11 Roy, Jean, R. Lecocq, A. Auger, “Development of a Collaborative Knowledge Exploitation Framework (CKEF) for the Maritime Domain Awareness Operations Centres and of a K-mapping Application: Progress Review Meeting,” Powerpoint slides, 25 April 2007

R-12 Hall, D.L. and J. Llinas, “Handbook of multisensor data fusion,” CRC Press, 2001

R-13 Lecocq, R., “Knowledge Mapping: A Conceptual Model,” DRDC Technical Report 2006-118, 2006

R-14 Roy, Jean, R. Lecocq, A. Auger, M. Morin, “Development of a Collaborative Knowledge Exploitation Framework (CKEF) for the Maritime Domain Awareness Operations Centres and of a K-mapping Application: Kick-Off Meeting,” Powerpoint slides, 9 Februry 2007

R-15 JTFA, “Commander’s concept of operations (CONOPS) Joint Task Force Atlantic,” JTFA: 3000-0 (J00), May 2006

R-16 site visit to JTFP, February 2007

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

R-17 Artificial Intelligence A Modern Approach. Stuart Russell and Peter Norvig. Pearson Education Inc. 2003.

R-18 Ontologies & Databases: Similarities & Differences Ontolog Panel. Dr. Leo Obrst MITRE Information Semantics Center for Innovative Computing & Informatics October 12, 2006.

R-19 C. Matheus, Using Ontology-based Rules for Situation Awareness and Information Fusion. Position Paper presented at the W3C Workshop on Rule Languages for Interoperability, April 2005.

R-20 C. Matheus, M. Kokar, K. Baclawski and J. Letkowski, Using SWRL and OWL to Capture Domain Knowledge for a Situation Awareness Application Applied to a Supply Logistics Scenario. In Proceedings of International Conference on Rules and Rule Markup Languages for the Semantic Web, RuleML-2005, Galway, Ireland, November, 2005

R-21 C. Matheus, B. Dionne, D. Parent, K. Baclawski and M. Kokar. BaseVISor: A Forward-Chaining Inference Engine Optimized for RDF/OWL Triples. In Digital Proceedings of the 5th International Semantic Web Conference, ISWC 2006, Athens, GA, Nov. 2006.

R-22 Gutierrez, C., C. Hurtado, and A. Vaisman, Temporal RDF, in European Conference on the Semantic Web. 2005: Heraklion, Crete, Greece.

R-23 Perry, M., F. Hakimpour, and A. Sheth, Analyzing Theme, Space and Time: an Ontology based Approach, in 14th ACM Int'l Symposium on Geographic Information Systems. 2006: Arlington, VA.

R-24 Hakimpour, F., et al., Data Processing in Space, Time and Semantics Dimension, in Terra Congita - Directions to the Geospatial Semantic Web. 2006: Athens, GA.

R-25 Perry, M., F. Hakimpour, and A. Sheth, P. Jain, What, Where and When: Supporting Semantic, Spatial and Temporal Queries in a DBMS, KNOESIS Technical Report KNOESIS-TR-2007-01, Dayton, OH

R-26 Davis, R., H. Shrobe and P. Szolovits What is a Knowledge Representation. Accessed at http://groups.csail.mit.edu/medg/ftp/psz/k-rep.html in June 2007

R-27 Furche,T., L. Benedikt, F. Bry, D. Plexousakis, G. Gottlob, RDF Querying: Language Constructs and Evaluation Methods Compared, Second International Summer School 2006, Lisbon, Portugal, September 4-8, 2006, Tutorial Lectures

R-28 Broekstra, A. Kampman. Inferencing and Truth Maintenance in RDF Schema: Exploring a Naive Practical Approach. In Workshop on Practical and Scalable

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

Semantic Systems (PSSS) 2003, Second International Semantic Web Conference, Sanibel Island, Florida, USA. See http://openrdf.org/doc/papers/inferencing.pdf.

R-29 Thompson, B., M. Personick, B. Bradley of SAIC, P. Bijan, C. Martyn , A High Performance RDFS Store using a Generic Object Model, Presented at Xtech 2006, Amsterdam. See http://xtech06.usefulinc.com/schedule/paper/126

Use, duplication, or disclosure of this document or any of the information contained herein is subject to the restrictions on the title page of this document.

MDA DISTRIBUTION LIST

NAME	COPY	NAME	COPY
Michael Mulder	X		
Harold Zwick	X	Jean Roy – SA	X
Christian Nadeau	X	Aline Brisebois – CA	X
Gary Reedel	X		
Michael Davenport	X		
MDA library - Synergy	X		

Use, duplication, or disclosure of this document or any of the information
contained herein is subject to the restrictions on the title page of this document.

DRDC Distribution list

Document No.: DRDC Valcartier CR 2007-175

LIST PART 1: Internal Distribution at DRDC Valcartier

1 - Head/Information and Knowledge Management Section
1 - Head/Decision Support Systems Section
1 - Head/System of Systems Section
1 - Mr Jean Roy (Already has a copy)
1 - Dr Alain Auger (Already has a copy)
1 - Mrs Régine Lecocq (Already has a copy)
1 - Mr Yaïves Ferland
1 - Dr Michel Gagnon
1 - Mr Denis Gouin
1 - Mr Alain Bouchard
1 - Mr Marc-André Morin
1 - LCdr Elizabeth Woodliffe
1 - Dr Pierre Valin
1 - Dr Adel Guitouni
1 - Mrs Micheline Bélanger
1 - Dr Anne-Claire Boury-Brisset
1 - Mr Martin Blanchette
1 - LCol Michel Gareau
1 - Mr Gaetan Thibault
1 - Mr Éric Dorion
1 - Mr Dany Dessureault

TOTAL LIST PART 18

LIST PART 2: External Distribution by DRDKIM

1 - Director – R&D Knowledge and Information Management

TRINITY Halifax
P.O. Box 99000 Stn Forces
Halifax, NS
B3K 5X5

1 - TRINITY Commanding Officer (CO)
1 - TRINITY Executive Officer (XO)

ATHENA Esquimalt
P.O. Box 17000 Stn Forces
Victoria, BC
V9A 7N2

1 - ATHENA Commanding Officer (CO)
1 - ATHENA Executive Officer (XO)

NDHQ
101 Colonel By Drive
Ottawa ON K1A 0K2

1 - Canada Command HQ – Joint Command Centre (JCC) – Director JCC
1 - Canada Command HQ – Joint Command Centre (JCC) – J3 Maritime
Directorate Science and Technology (Maritime)
1 - Attn: Dr Pierre Lavoie (DSTM)
1 - Attn: Mr Greg Walker (DSTM 3)
1 - Attn: Mrs Laura Ozimek (DSTM 5)
Centre for Security Science (CSS)
1 - Attn: Dr Anthony Ashley – Director General
1 - CMS – DGMFD – DMRS 2 (Maritime Security Section Head)
1 - CMS – DGMFD – DMRS 2 (Project Director MSOC)

DRDC Atlantic
9 Grove Street
Dartmouth NS B2Y 3Z7

1 - Dr Ross Graham – Director General – DRDC Atlantic (Scientific Advisor (Maritime))
1 - Cdr Siegfried Richardson-Prager (SMO)
1 - Mr Jim S. Kennedy (Thrust Leader "11h")
1 - Dr Mark McIntyre
1 - Mr Dave Chapman
1 - Mrs Liesa Lapinski
1 - Mr William Campbell

DRDC Ottawa
3701 Carling Avenue
Ottawa ON K1A 0Z4

1 - Mr Gary Geling
1 - Mr Rick Brown
1 - Mr Chris Helleur
1 - Mr Dan Brookes
1 - Mr David DiFilippo

TOTAL LIST PART 25

TOTAL COPIES REQUIRED: 43

DOCUMENT CONTROL DATA

1. ORIGINATOR (name and address) MacDonald Dettwiler and Associates Ltd 13800 Commerce Parkway Richmond, BC, Canada V6V 2J3	2. SECURITY CLASSIFICATION (Including special warning terms if applicable) Unclassified

3. TITLE (Its classification should be indicated by the appropriate abbreviation (S, C, R or U)
Comparative Study of Formal Knowledge Representation Enablers for the Collaborative Knowledge Exploitation Framework (U)

4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.)
Reedel, Gary

5. DATE OF PUBLICATION (month and year) July 2007	6a. NO. OF PAGES 73	6b .NO. OF REFERENCES 29

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. Give the inclusive dates when a specific reporting period is covered.)
Technical Report

8. SPONSORING ACTIVITY (name and address)
N/A

9a. PROJECT OR GRANT NO. (Please specify whether project or grant) DRDC Project 11hg	9b. CONTRACT NO. W7701-062549/001/QCL
10a. ORIGINATOR'S DOCUMENT NUMBER CKEF-RP-52-5274	10b. OTHER DOCUMENT NOS DRDC Valcartier CR 2007-175

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

- ☒ Unlimited distribution
- ☐ Restricted to contractors in approved countries (specify)
- ☐ Restricted to Canadian contractors (with need-to-know)
- ☐ Restricted to Government (with need-to-know)
- ☐ Restricted to Defense departments
- ☐ Others

12. DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in 11) is possible, a wider announcement audience may be selected.)
Unlimited Anouncement

13. ABSTRACT (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

This is a report describing a comparative study of formal knowledge representation enablers for the collaborative knowledge exploitation framework (CKEF). This reports introduces the requirements for knowledge representation and presents a brief description of background technology and several research programs applicable to the CKEF. A summary review of the technology enablers is presented in this report, along with a selection of enablers products that are evaluated against a standard set of criteria. Finally, some recommendations for the best candidate enabler technologies are provided for the CKEF.

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

Maritime Awareness
Knowledge Management
Knowledge Exploitation
Knowledge Representation
Ontology
Knowledge Representation Enablers