"Knowledge Enabled Services (KES) for Decision Support in Control Rooms. CESADS(KES) Case Study at ESA/ESOC."

J. Busto[1], J. Varas[1].

[1] GTD, Sistemas de Información, SAU., Barcelona, Spain

ABSTRACT

This paper describes an innovative yet operational knowledge-based Monitoring, Diagnostic and Decision Support system aimed to increase operational efficiency and knowledge preservation in complex control rooms under conditions of stressed operation. The system fixes current difficulties in terms of (1) homogenization of operator's knowledge and (2) management of complexity derived from large systems resulting from a progressive and accumulative deployment.

The paper discusses the combination of Knowledge Technologies addressing main issues in the control room: structural (domain) knowledge and behavioural (reasoning) knowledge. Conceptually, the paper describes the organization and construction of knowledge models on top of Ontologies and Production Rules (using Fuzzy Logic). The paper does also address the design of specific, operator-adapted human machine interfaces for the definition, maintenance and evolution of modular and hierarchical set of formalized knowledge. The paper depicts implementation of the Knowledge Enabled Service (KES) based on the integration of Protégé and Jess tools, which are integrated into multi-client distributed architecture with modular client applications for system interaction, including a key Knowledge Acquisition Module (C-KAE). Additionally, the paper introduces the demanding methodological approach which has result from the combination of the CommonKADS framework - for the Knowledge Engineering tasks - with the Rational Unified Process.

The paper includes detailed description of an operative Case Study: the CESADS project, a KES Decision Support System (DSS) implemented at ESOC for monitoring, prediction and diagnostic of very critical end-to-end space link (S/L) losses in spacecraft control missions, with high stress and responsiveness requirements on operators. The paper discusses the development and implantation of the pre-operational tool and focus on lessons learnt.

Accordingly, the paper elaborates further the evolution of the knowledge and software engineering frameworks via Ontologies (on top of the W3C's RDF and OWL specs), WebServices, Grid and SemanticWeb, into the emerging and unifying Semantic-Grid paradigm.

Keywords: KES, Decision Support, ESA, ESOC, CommonKADS, Ontology.

1 CONTEXT

The European Space Agency (ESA), from its Space Operations Center (ESOC) located in Darmstadt (Germany), is able to operate up to 15 Spacecraft (S/C) missions in parallel, controlling remotely a worlwide network of Ground Stations (G/S) called the European Space Tracking Network (ESTRACK), as illustrated in Fig. 1.

ESTRACK operators at ESOC face a range of critical and knowledge intensive tasks along the spacecraft (S/C) mission control process. A main critical task is to guarantee the maintenance of the end-to-end Space Link (S/L). This end-to-end S/L involves a number of different and yet independent systems such as the Flight Dynamics, the Ground Station scheduling and configuration system (CSMC), the wide area network management system (NMS), and the spacecraft mission control system (MCS). In addition, the increase of the number of missions and the high frequency of pass over the Ground Stations of low orbit satellites (like ENVISAT) increases the stress and responsiveness requirements over ESOC operators.

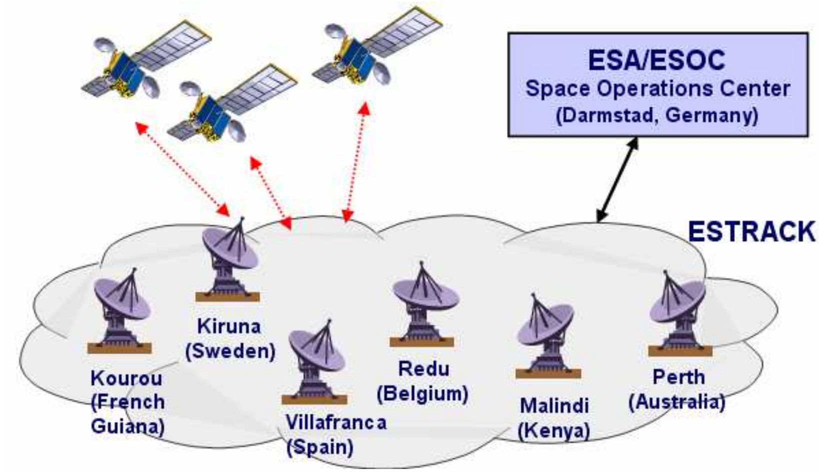

Fig. 1 The ESA European Space Tracking Network (ESTRACK).

2 PROBLEM ADDRESSED

Under this context, the ESA/ESOC started CESADS (Centralised ESTRACK Status and Diagnostic System) as a R&D Project with the goal of demonstrating, with an operative software system, the capabilities and benefits of applying state-of-the-art *knowledge technologies & engineering* to support ESOC/ESTRACK operators during the satellite control missions. Thus, CESADS is posed as a knowledge-based system focusing on the following main issues:

- S/L Maintenance: Enhanced Monitoring and Diagnostic of the S/L Status.
- Knowledge Management: Capture, Maintain, and Apply the Knowledge of the experts. An important aspect is the fact that many failure diagnostics and troubleshooting knowledge is tacit knowledge (not explicit) in the head of the most experienced operators.
- System Level Integration: Integration and processing of the data from the several existing systems (e.g. MCS, CSMC, and NMS). These systems are actually independent.
- Enhanced Anomaly Analysis: Prediction of component failures and anticipation in detection.

3 METHODS & SOLUTION APPROACH

Knowledge Technologies (KT)

The most relevant KT applied have been: Ontologies for the representation of the Domain Knowledge, and Production Rules with Fuzzy Logic for the representation of the alarms and behaviour knowledge. The implementation of these technologies has been based on the integration of two Java software COTS: 1) (Fuzzy)Jess, the Java Expert System Shell (from Sandia labs) for rule based reasoning; and 2) Protégé (from Standford SMI), which provides three main functions: a) a frame-based/ontology modelling, b) automatic building of knowledge acquisition forms, and c) knowledge base serve platform that can be integrated in larger scale systems.

Knowledge Engineering (KE) methodology

For the Knowledge Engineering tasks, the project has followed the CommonKADS framework. CommonKADS is a methodology that is considered a European de facto standard for knowledge analysis and knowledge-intensive system development. It facilitates to spot the opportunities and bottlenecks in how organizations develop, distribute and apply their knowledge resources, and so gives tools for corporate knowledge management. It also provides methods to perform a detailed analysis of knowledge-intensive tasks and processes, and to develop knowledge systems that support selected parts of the business process.

CommonKADS distinguishes the following types of knowledge intensive tasks, and provides a *Knowledge Model Template* for each of them: on one hand Analytic Tasks: Classification, Assessment, *Diagnosis*, *Monitoring*, Prediction; and on the other Synthetic Tasks: Design, Modelling, Planning, Scheduling, Assignment. In CESADS, a variation based on Benjamins´ library of Problem Solving Methods (as shown in Fig. 2) has been applied for the Monitoring and Diagnostic task. The basic functions of this method are: 1) Symptom detection: Takes an observation as input and determines whether it is normal or abnormal; 2) Hypothesis generation: Takes the set of initial observations, divided into normal and abnormal, and outputs a set of hypotheses that each explains the initial observations; 3) Hypothesis discrimination: Prunes the set of hypotheses by making additional observations. The figure also shows how the Fuzzy Logic Rule based techniques are applied along the functions of the process template.

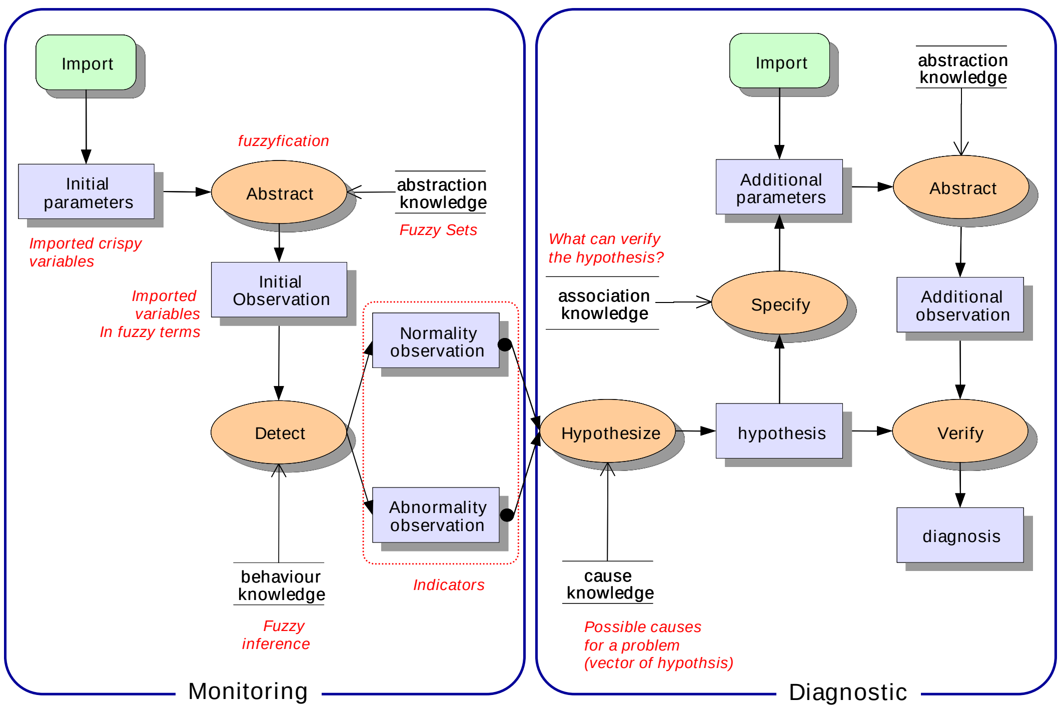

Fig. 2 CommonKADS Knowledge Model Template for Monitoring and Diagnostic analytic tasks. Rounded-squares are transfer functions, ovals are Inferences, and squares are domain concepts.

Design Model

In terms of software artefacts (Design Model), a usual pattern for Knowledge Base System is as shown in Fig. 3.

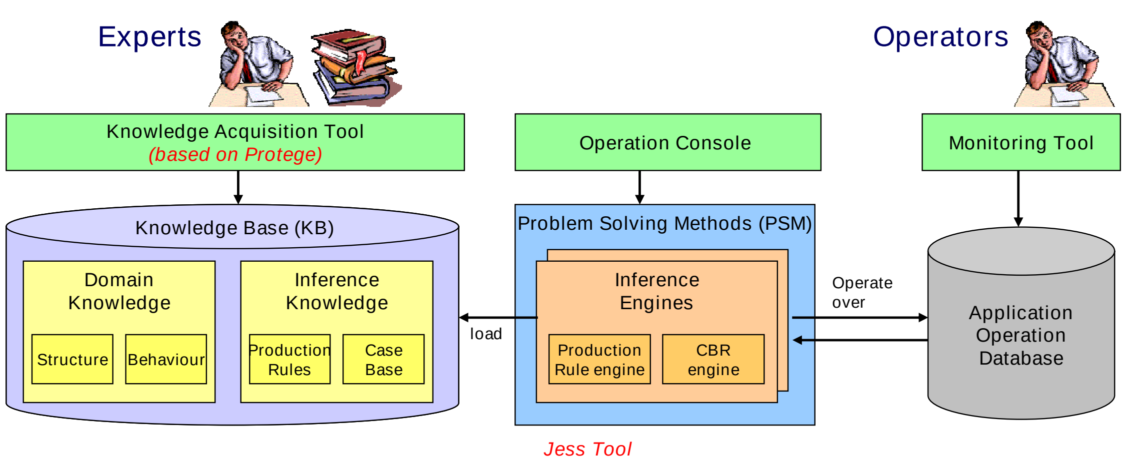

Fig. 3 Knowledge Base System Design Model.

Software Engineering methodology

In a combined way with CommonKADS, a*gile methods* (iterative) have been applied for the software engineering tasks. In particular Rational´s RUP and the three iteration phases as proposed by the DSDM Consortium: Functional, Design and Operational Prototype (see Fig. 4). In terms of software technology, the developments are based on the J2EE reference architecture, with the following patterns as the most relevant: Model-View-Control, RMI-based observable-observer for communications between the Monitoring tool and the server, and the Blackboard pattern (the Inference Engines are Knowledge Sources).

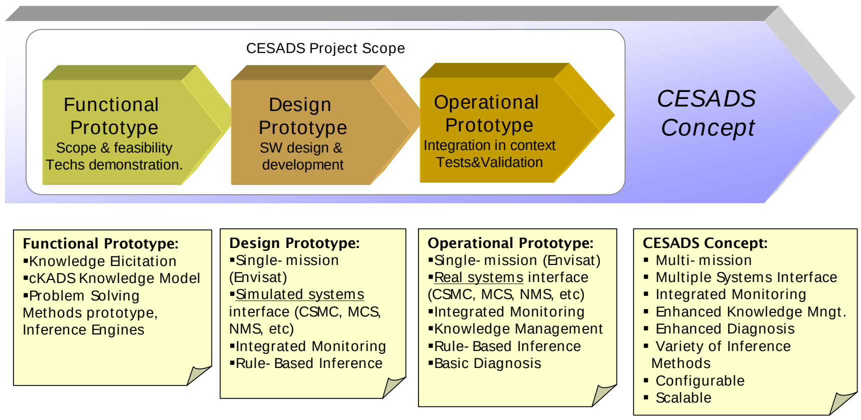

Fig. 4 Iterative system development, following Agile DSDM approach.

4 RESULTS

The CESADS Prototype System is composed by three main parts: External Data Importers, CESADS Sever, and multiple CESADS Clients applications. The External Data Importers gather data from the actual external control systems (CSMC, NMS, MCS). The CESADS Sever is the core of the system and the central processing and inference engine. It operates on all collected data from the several control systems and executes the monitoring & diagnostic workflows and inference processes. The prototype has been designed so as to be a complete multi-client distributed system, having four main types of clients applications: C-SLAM is the Space Link Assessment and Monitoring Tool. It allows to visualise all the defined indicators, and retrieve the rules and input facts that produced that indicators; C-KAE is the Knowledge Acquisition Environment, for maintenance of the knowledge base; C-RET is a Reporting Tool for generation of alarm & inference reports, knowledge reports, etc., and C-MAT is Management Tool for administration of users, servers status.

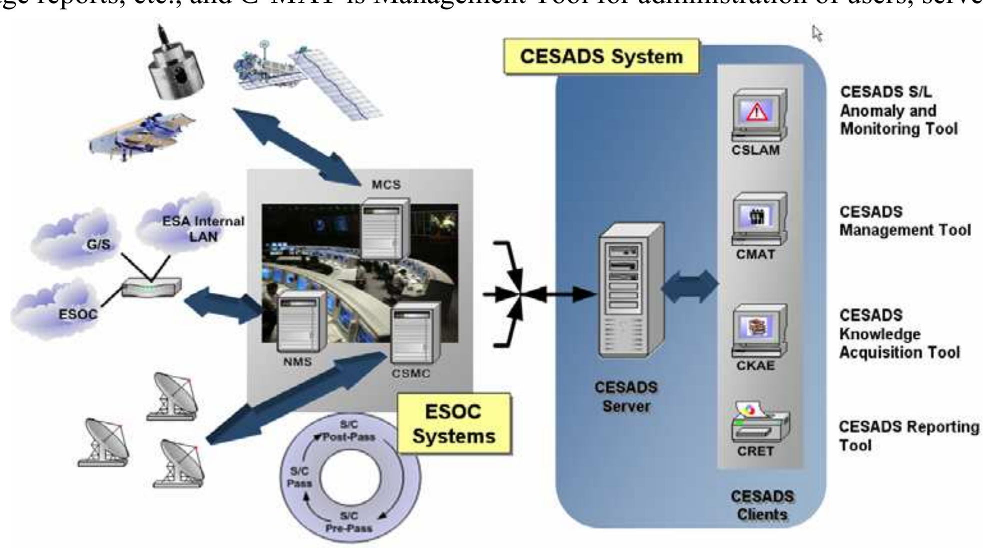

Fig. 5 The CESADS System concept.

The Knowledge Model: Fig. 6 shows a representation in UML syntax of the Knowledge Model developed with the Protégé tool. It represents therefore the data model of the Knowledge Base System. On the basis of this model, the expert user is able to define: 1) the catalogue of Fuzzy Sets and Fuzzy terms to enable the mapping of quantitative values of parameters into qualitative fuzzy terms; the hierarchy of Elements & sub-Elements of the domain (ESTRACK), and its associated Parameters, either imported Variables or inferred Indicators; the Processes, either Import Process to get data from external systems, or Inference Processes to produce new Indicators. Note that this Knowledge Model is generic and valid to model any complex systems, besides of ESTRACK.

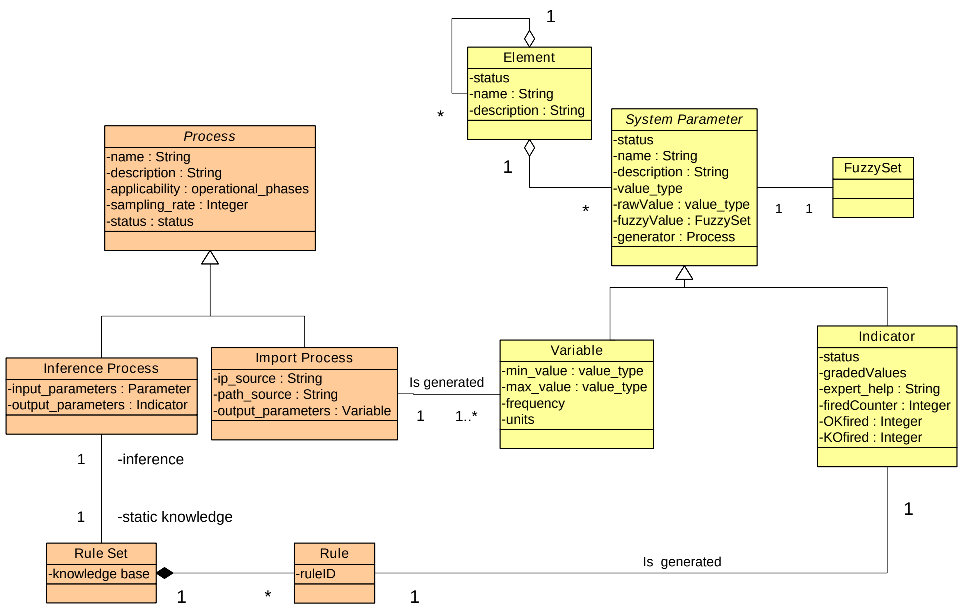

Fig. 6 The Knowledge Model.

C-KAE Interface. Correspondingly to the model, the C-KAE provides a graphical user interface (see Fig. 7) for the definition of modular and hierarchical set of inference rule-based knowledge models, resulting in a *Knowledge Model Driven* high-level Alarm generation approach.

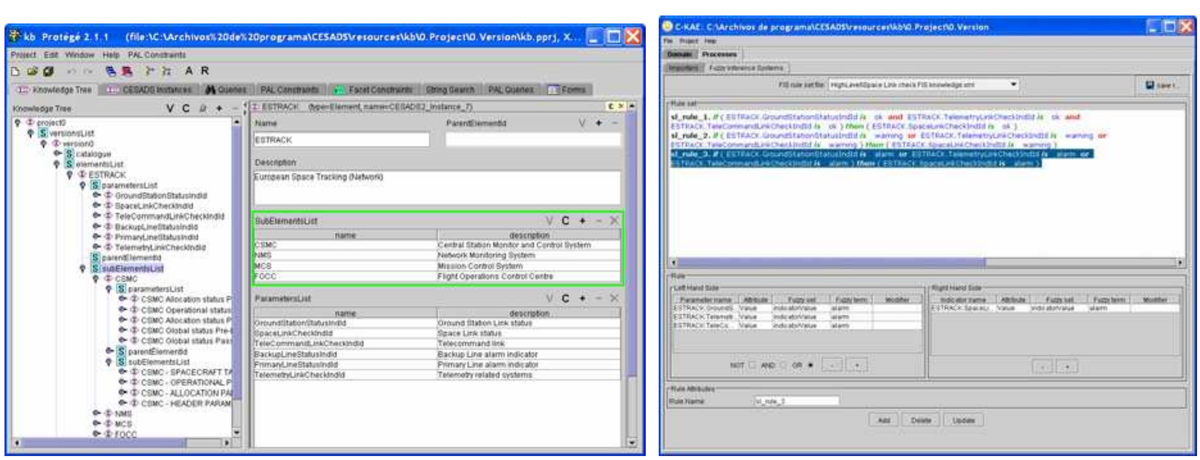

Fig. 7 The C-KAE user interfaces. Domain structure and fuzzy rule sets edition.

C-SLAM interface. The C-SLAM provides different panels. The main one is the c-slam-synoptic. It shows pre-defined alarms (ESTRACK specific) which will be the basis for the operator monitoring. The operator will monitor these alarms on the basis of the meaning that the domain expert (supported by the knowledge engineer) has assigned to the alarm indicator. Another important panel is c-slam-table, which complements the synoptic with generic and configurable tables that enable to inspect the historic of generated indicators, to retrieve its associate origin data, and (*planned*) to get formal (ontology-enabled) operator ´s feedback about the generated indicators.

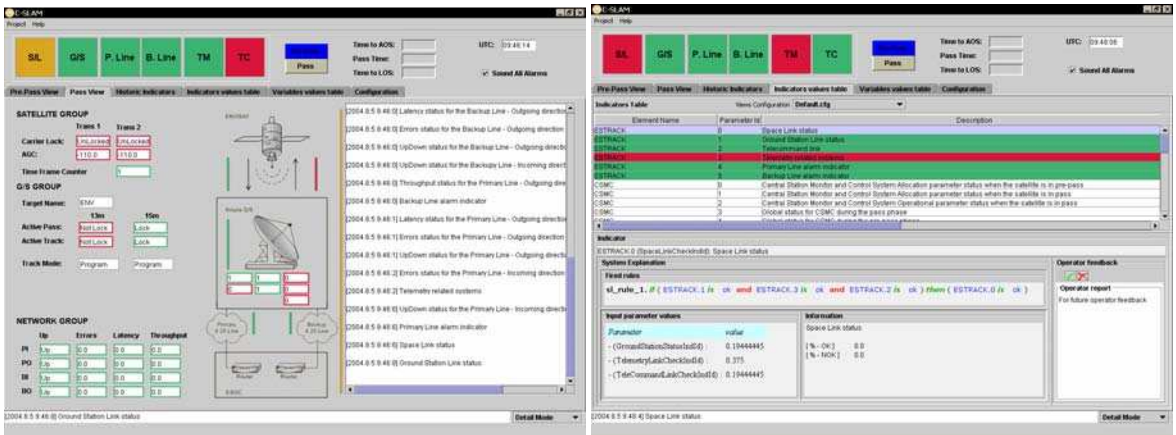

Fig. 8 C-SLAM interface. Synoptic and table views..

5 CONCLUSIONS

Methodologically, it can be said that CommonKADS has been proved as a valid Knowledge Management and Engineering approach. The knowledge technologies applied have also provided added value, being the system able to generate high-level *qualitative indicators* that offer an integrated view of the status of the entire complex system (ESTRACK). It must be said however the usual problem of the *knowledge acquisition bottleneck* is still an issue since the effort of a domain expert & knowledge engineer is needed to tune the system knowledge to a useful level.

Nevertheless, the most significant conclusion is in the aspect of software evolution of the platform, particularly due to the very recent and strong emergence in the IT mainstream of the Ontology and SemanticWeb vision. In this area, the W3C´s RDF/OWL-XML languages represent a new enabling technology for semantic interoperability and sharable knowledge representation. Ontologies are also enabling extensions to other key web-based technologies and protocols like Semantic Web Services, or the BPEL4WS standard for workflows. The used tools (Protégé, Jess) support this technology migration, being Protégé (with its OWL plug-in based on the Jena framework from HP Laps) one of the most-widely used ontology modeling tools. Triggered by all this, a deep platform evolution is envisioned towards a concept of "Knowledge Enabled Services (KES) Grid", as illustrated in Fig. 9.

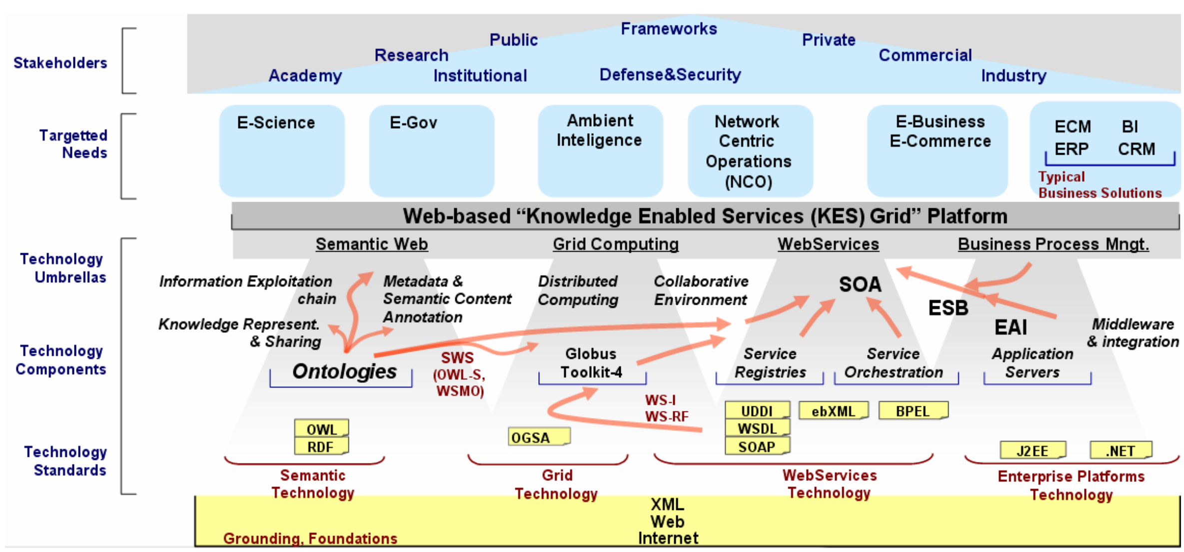

Fig. 9 Convergence of technologies towards a "Knowledge Enabled Services (KES) Grid" concept.

In this context, the CommonKADS framework, with its models and templates, can be applied using this new Semantic Service Oriented Architecture approach, thus enabling a new generation of KES for Decision Support in Control Rooms.